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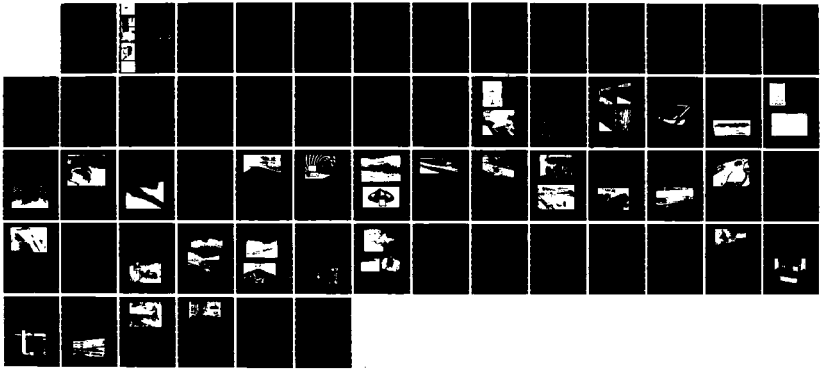

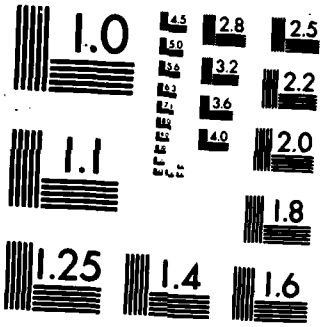

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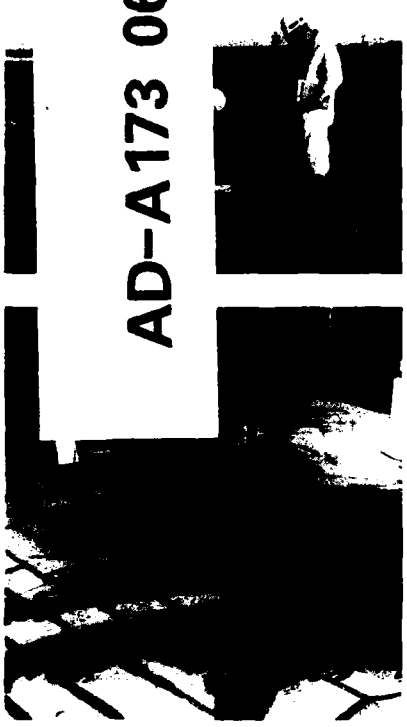

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A CAPSULE OF CIVIL WORKS RESEARCH AND DEVELOPMENT 1977-1986

by

Alfred W. Ford

Office of Technical Programs and Plans

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

October 1986
Final Report

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Civil Works Research and Development Programs seek solutions to national, regional, and local problems related to water and water-related resources management and development. Typically, the Corps of Engineers has undertaken numerous projects, such as (1) improved flood control and damage mitigation by constructing dams, reservoirs, levees, floodwalls, channel improvements, and diversions; (2) improved commercial and recreational navigation in harbors, channels, canals, and inland, intracoastal, and coastal waterways; (3) improved erosion control and shore protection, including inland and coastal beaches, and river channel and bank stabilization; (4) improved water-oriented recreational opportunities; (5) improved municipal and industrial water supplies; (6) pollution abatement; and (7) preservation and enhancement of fish, wildlife, and aesthetic, cultural, and other environmental values.

Research and development by the Corps of Engineers provides essential support to these Civil Works missions by finding solutions to the many technical, safety, environmental, and economic problems which arise during the life of a project from its planning and design to its construction and operation and maintenance. Keywords:

The progress of the Corps of Engineers in attaining these objectives over the last ten years is measured in this report.

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PREFACE

Civil Works Research and Development Programs seek solutions to national, regional, and local problems related to water and water-related resources management and development. Typically, the Corps of Engineers has undertaken numerous projects, such as (1) improved flood control and damage mitigation by constructing dams, reservoirs, levees, floodwalls, channel improvements, and diversions; (2) improved commercial and recreational navigation in harbors, channels, canals, and inland, intracoastal, and coastal waterways; (3) improved erosion control and shore protection, including inland and coastal beaches, and river channel and bank stabilization; (4) improved water-oriented recreational opportunities; (5) improved municipal and industrial water supplies; (6) pollution abatement; and (7) preservation and enhancement of fish, wildlife, and aesthetic, cultural, and other environmental values.

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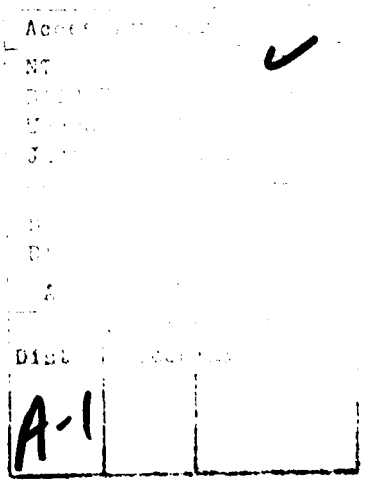
The progress of the Corps of Engineers in attaining these objectives over the last ten years is measured in this report.

This report was written by Mr. Alfred W. Ford, Office of Technical Programs and Plans, US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. Mrs. Jamie W. Leach of the WES Information Technology Laboratory (ITL) edited this report. Mrs. Loriece M. Beall of ITL designed and composed the layout.

COL Dwayne G. Lee, CE, is the Commander and Director of WES. Dr. Robert W. Whalin is the Technical Director.



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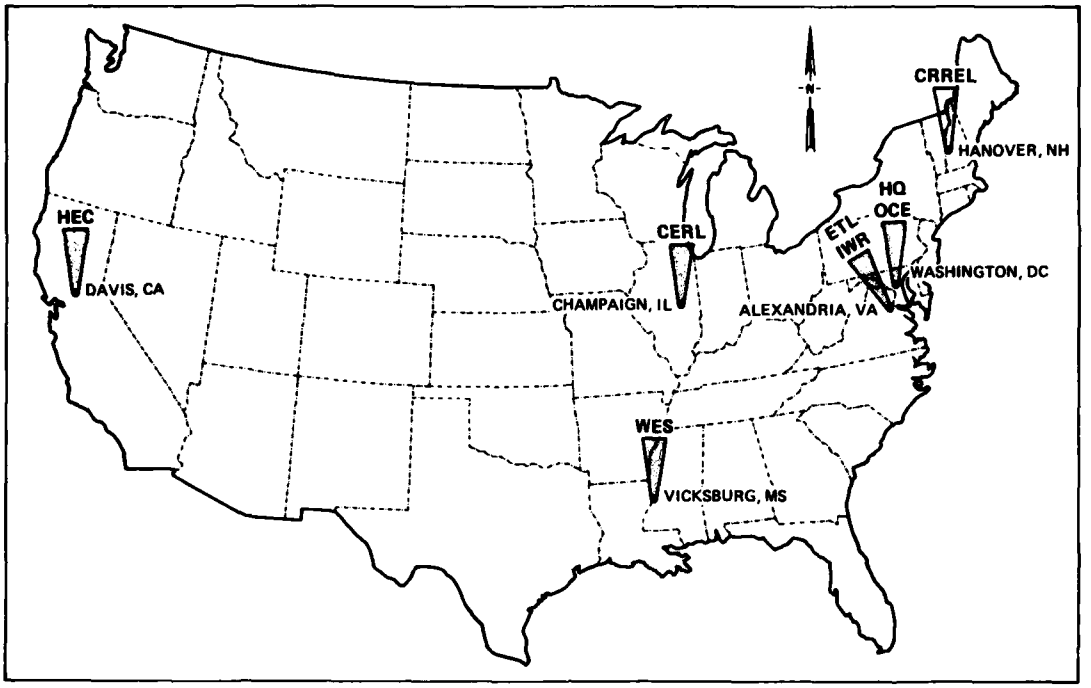
Part I
INTRODUCTION

Research and development (R&D) underpins the Civil Works program by improving the Corps of Engineers' capability to accomplish its water resources mission and program with optimum effectiveness, economy, and safety, and with effective concern for protection or enhancement of environmental and social values. Some of these evolve from new Executive Orders, legislative requirements levied through other agencies, and regulatory standards imposed against projects constructed prior to the establishment of such standards. With comprehensive planning and with concern for mitigation of environmental impact and energy conservation, the Civil Works research program is strongly addressing problems generated by these concerns. Because of the increasing age of more and more Corps water resource facilities, greater emphasis is being placed on R&D concerning the repair, evaluation, maintenance, and rehabilitation of these water resource facilities.

The R&D effort is a highly applied effort, utilizing in part products and techniques developed by industry and universities, and adapting them to Civil Works needs. This R&D effort is essentially a "problem solving" process by which the Corps systematically examines new ideas, approaches, and techniques, with a view toward improving the efficiency of its planning, design, construction, operations, and maintenance activities. In considering the Civil Works R&D program against the background of the overall mission it supports, it should be noted that this mission is the most widespread and varied of the several Federal water resources programs. Yet, in comparison to many other Federal agencies and private industry, the Corps of Engineers spends very little on R&D.

The Corps manages and conducts Civil Works R&D through its four research centers: the Cold Regions Research and Engineering Laboratory at Hanover, New Hampshire; the Construction Engineering Research Laboratory at Champaign, Illinois; the Waterways Experiment Station at Vicksburg, Mississippi; and the Engineer Topographic Laboratories at Fort Belvoir, Virginia. Some elements of Civil Works R&D are also assigned to the Corps' Institute for Water Resources at Fort Belvoir, Virginia, and the Hydrologic Engineering Center at Davis, California. Approximately 65 percent of the current research effort is accomplished in-house and the remainder is performed by universities, other government agencies, or private firms.

If the Corps is to take advantage of rapidly developing technologies and techniques which offer the possibility of significant monetary savings and greater reliability, safety, and overall effectiveness, it must pursue an aggressive R&D effort. The added complexities of environmental and social considerations, the mounting concern with urban problems, and the urgent requirement to balance the Federal budget and get the maximum return for every Federal dollar



US Army Corps of Engineers research and development community.

spent necessitate, more than ever, increased emphasis on new approaches and methods.

The US Army Cold Regions Research and Engineering Laboratory (CRREL) conducts R&D in support of a broad range of Civil Works mission areas which include ice engineering, river ice management, Civil Works remote sensing, and cold regions hydrology.

The US Army Construction Engineering Research Laboratory (CERL) is engaged in R&D of building materials, utilities, and structures; integrating technological developments into construction; and developing and evaluating the principles of systems engineering and applying the systems approach to the life-cycle requirements of facilities and their management. The life cycle includes all the processes from planning, design, and construction, through operation, maintenance, and replacement.

The US Army Engineer Waterways Experiment Station (WES) is the largest R&D and testing complex of the Corps. The functional organization of the WES includes six engineering laboratories: Hydraulics, Geotechnical, Structures, Environmental, Coastal Engineering Research Center, and the Information Technology Laboratory. Its Hydraulics Laboratory is large and well equipped with approximately 60 active models of river basins, dams and reservoirs, navigation locks, estuaries, and harbors. In addition, extensive capabilities exist in numerical hydrodynamic modeling. These models have resulted in improved methods of flood control, safer navigation facilities, conservation of water resources, safer and cleaner harbors and waterways, more efficient and less costly hydraulic structures, protection and improvement of the environment, and

other related benefits. WES is also engaged in R&D, engineering investigations, and other testing and studies in the fields of soil and rock mechanics, earthquake engineering, foundations, engineering geology and geophysics, portland cement and bituminous concrete, aquatic plant control, dredging technology, water quality improvement, and environmental sciences. The prevailing mild climate at this facility permits almost uninterrupted outdoor testing throughout the year. The Coastal Engineering Research Center (CERC) has recently been moved from Fort Belvoir, Virginia, to WES. This move has achieved economies and strengthened the Corps' coastal engineering research program. As one of the laboratories at WES, CERC will continue to conduct R&D to provide a better understanding of shore processes, winds, waves, tides, surges, currents, and materials as they apply to navigation improvements, flood storm protection, beach erosion control, recreation, and protection of structures in the coastal zone.

The US Army Engineer Topographic Laboratories (ETL) accomplishes research, development, testing, and evaluation of systems, equipment, procedures and techniques applicable to the terrestrial and topographic sciences.

The US Army Engineer Institute for Water Resources (IWR) is concerned with comprehensive river basin and regional planning, formulation, and evaluation of proposed projects and project-systems, including consideration of nonstructural alternatives as well as identification and evaluation of applicable economic, social, and environmental factors. IWR also evaluates education and training needs and capabilities for water resources planners, develops and administers training programs for planners, and monitors utilization of trained planners throughout the Corps.

The US Army Engineer Hydrologic Engineering Center (HEC) concentrates on four functional areas: R&D, training, methods systematization, and technical assistance and advice to field offices. Hydrologic engineering R&D conducted or administered by HEC supplements relevant research in universities and other organizations to meet the practical needs of Corps field offices. Training activities, primarily in the form of short-course modules, are designed to provide Corps employees with information on both basic and advanced techniques in hydrologic engineering. The development of a library of generalized computer programs in hydrologic engineering, and the development of procedures for expanding the use of statistical analyses and stochastic variations in planning, design, and operation of water resources projects and systems, are major components of the methods systematization program. Under its technical assistance program, HEC advises Corps field offices on the application of new or unfamiliar procedures for the solution of hydrologic problems in multipurpose projects, the estimation of flood frequency and flood magnitude, and the analysis of hydrologic and economic consequences of channel improvement.

Part II
SAVINGS THROUGH CIVIL WORKS RESEARCH

One of the most meaningful measures of the value of research is the benefits, both monetary and intangible, which accrue through applications of the knowledge developed.

Not every research project will produce savings that are easily translated into dollars; some will serve to augment existing confidence in current techniques or designs, and others will better establish the degree of safety vital to large water resources development structures. Some may result in increased project construction or operational costs, although the safety or service life will be enhanced.

Results of research studies which were applied to the planning, design, construction, and operation of actual structures or projects were evaluated by the District offices of the Corps of Engineers, and the composite benefits are shown in the following tabulation. The monetary values represent savings realized only during the 1977-1986 decade. Benefits cited are limited to those directly applicable to Civil Works functions, and no attempt was made to incorporate instances where results were possibly utilized by the military or other governmental agencies or by industry.

Even though the cited cost savings in the following paragraphs exceed $500 million, no attempt was made to include all of the Corps' Civil Works Research Program results which have produced cost savings for this period. Only a few examples have been cited that significantly demonstrate the fact that not only does each program have a cost-benefit ratio that has provided a substantial return on investment to date, but they also provide savings on a continuing basis at a rate conservatively estimated to exceed $82 million per year. These savings have resulted from a total research investment of $185 million for the cited 10-year period.

Savings of Civil Works Research, 1977-1986

Problems Addressed	*Solution*	*Savings*
Research Area: Materials		
Program: Soils		
Design and construction of embankments on soft and failed foundations	Developed methodologies for analytical, quality control, and performance monitoring.	$1,270,000 on one prototype structure
Liquefaction of soils during earthquakes	Improved physical and analytical testing procedures for evaluating liquefaction susceptibility	$20,000,000 failure prevented at one structure
Inability to predict earthquake-induced sliding of dams and embankments	Improved testing procedures for analyzing possible sliding displacements	$15,000,000 elimination in dynamic analyses at 30 dams

Savings of Civil Works Research, 1977-1986 (Continued)

Problems Addressed	*Solution*	*Savings*
Program: Soils		
Uncertainties in methods for compaction control of soils containing oversized particles	Improved laboratory and field procedures to account for effects of oversized particles on moisture-density relationships	$750,000 on one project

Intangible Benefits Realized

If these capabilities had been available in the 1958-1960 period, the failure of Waco Dam could have been prevented with realizable costs savings of $11,000,000. These improved technologies provide greater reliability with respect to performance and safety, reducing the potential for similar or more catastrophic failures.

Program: Rock		
Safety of life and functional capability of large engineering projects, particularly major dams, susceptible to earthquakes	Provided state-of-the-art methods for evaluating seismic hazards	Intangible
Reliable stability assessment of new and existing structures under expected prototype loading conditions	Developed procedures for selecting design shear strengths for sliding stability assessments	Intangible
Inadequate testing equipment and procedures for determining the permeability of rock masses	Developed new equipment and procedures which greatly improve the understanding of water flow in rock masses	$120,000 annually

Intangible Benefits Realized

Specific savings are intimately correlated with probabilities of earthquake occurrence near structures incorporating design features and modifications. To date no Corps of Engineers dam has failed because of an earthquake but to put some perspective to the consequence of a dam failure, the cost associated with a major failure is estimated to be several hundred million dollars with an associated loss of scores of lives. Replacement cost is also estimated to be several hundred million dollars.

Program: Concrete		
Lack of economical mass concrete dam construction methods	Developed procedures for using roller-compacted concrete (RCC)	$2,000,000 on Willow Creek Dam
Determination of the earliest time that form work can be safely removed from concrete	Developed methods for the early removal of concrete forms based on concrete temperature exposure equated to strength gain	$500,000 annually
Construction and repair of stilling basins	Developed methods for using high strength silica fume concrete	$100,000 annually per application (there are 20 stilling basins requiring repair currently)

Savings of Civil Works Research, 1977-1986 (Continued)

Problems Addressed	*Solution*	*Savings*
	Program: Concrete	
Determination of the spacing and size of dowels needed to anchor replacement concrete to vertical walls of navigation locks	Developed design procedures which use one fourth as many dowels as before	$1,200,000 annually
Inability to inspect stilling basins and lock chambers while filled	Developed a high-resolution acoustic mapping system for assessing underwater structures without dewatering the project	$250,000 per application
Lack of use of high-range water-reducing admixtures	Developed methodologies for using these admixtures in certain classes of concrete	$750,000 annually
Lack of an evaluation of nonmetallic water stops	Standardized Corps specifications for the use of nonmetallic water stop and joint material	$175,000 annually

Intangible Benefits Realized

Intangible benefits result from an improved understanding of concrete construction materials and techniques which translates to safer and more economical and durable structures.

	Program: Structural Engineering	
Unavailability of computer-aided structural engineering techniques for Civil Works projects	Developed and released 39 structural engineering computer programs	$6,000,000 annually
Unavailability of guidance and simplified analytical procedures for designing and analyzing hydraulic structures	Developed computer programs to analyze two-dimensional geometry, shallow foundation problems, and soil-structure interaction of sheet walls and axially loaded piles	Intangible
Lack of design guidance for gravity dams subjected to seismic loads	Developed a simplified procedure for the seismic design of nonoverflow monoliths	Intangible

Intangible Benefits Realized

Indirect monetary savings will be realized throughout the design life of concrete gravity dams as these methods are used to assess the safety of massive concrete structures.

	Program: Electrical/Mechanical	
Lack of adequate design criteria for pumping stations sumps and discharge outlets	Developed new design guidance for sump geometry, pump location, and pump intake shape to achieve improved performance	$500,000 annually
Corrosion-related failures at locks and dams	Determined cause of failures and recommended corrosion-resistant materials for five specific installations	$6,300,000

Savings of Civil Works Research, 1977-1986 (Continued)

Problems Addressed	*Solution*	*Savings*
Research Area: Coastal Engineering		
Program: Coastal Flooding and Storm Protection		
Inability to predict shallow water waves	Instituted a long-term data collection program and developed numerical models for natural waves	$2,500,000 annually
Lack of laboratory simulation of directional spectral waves in physical models	Used the new directional spectral wave generator to improve ability to simulate "real world" waves	$3,000,000 annually
Lack of sufficient high-quality, long-term field data	Instituted a long-term meteorological and oceanographic data collection program for use in model evaluation	$300,000 per application
Inability to determine the cause of the hurricane-induced forerunner surge	Developed a numerical model to determine the magnitude and extent of the forerunner surge which resulted in less costly coastal structures	$500,000 annually
Unavailability of coastal numerical models	Developed a user-friendly model system which provides solution algorithms for various coastal numerical models	$9,000,000 annually

Intangible Benefits Realized

Damage and morphological changes to coastal areas are most pronounced during severe episodic events. Heretofore, acquisition of prototype data were rarely successful because available techniques were inadequate. Development of new techniques and equipment have made data acquisition possible resulting in a better understanding of the physical processes occurring during severe events.

Program: Harbor Entrances and Coastal Channels		
Lack of knowledge for predicting wave conditions and interactions in harbor entrances and inlets	Developed hybrid numerical models to predict wave conditions and wave interactions in harbor entrances and inlets	$4,200,000 annually
Lack of information for determining the stability of natural and dredged channels and ebb tidal delta evolutionary sequences	Standardized methods for predicting shoaling rates; developed analytical techniques for predicting shoaling rates in tidal inlets	$7,000,000 annually

Savings of Civil Works Research, 1977-1986 (Continued)

Problems Addressed	*Solution*	*Savings*
Program: Shore Protection and Restoration		
Inadequate design criteria for determining the stability of beach fills	Developed methods for determining optimum borrow material, overfill factors, and berm elevations and widths for shore slopes, and for determining feeder beach location	$1,800,000 annually
Inadequate design criteria for groins, offshore breakwaters, and other shore protection structures	Developed numerical models to determine shoreline responses to various coastal structures	$5,000,000 annually
Inability of existing engineering formula to predict long-shore sand transport rates	Used advanced instrumentation to provide more accurate estimates of sand transport rates	$3,500,000 annually

Intangible Benefits Realized

Research has provided guidance for evaluating existing beaches in terms of expected storm erosion. This guidance provides a rational basis for estimating both sand replenishment needs and quantities. It also permits rapid estimates of storm damage for emergency planning. Better design of the Grand Isle, Louisiana, hurricane protection dune system could have saved an estimated $2.5 million (one fourth the project cost) of the damages caused by Hurricane Juan in 1985.

Program: Coastal Structure Evaluation and Design		
Lack of design criteria for detached breakwaters	Developed design guidance for detached breakwaters	Intangible
Lack of economical techniques to inspect and evaluate the condition of coastal structures	Developed methodologies for evaluating coastal structures using a side-scan sonar	$600,000 annually
Inadequate computational and design methods for use on coastal projects	Produced four editions of the *Shore Protection Manual* and numerous technical reports, Coastal Engineering Technical Notes, and Microcomputer Applications for Coastal Engineering to update engineering guidance and to improve computations and consideration of alternate designs	$3,000,000 annually
Determination of internal structural load-carrying requirements of concrete floating breakwaters	Developed improved structural design criteria	$1,720,000 for two projects
Determination of stability coefficients for various types of breakwater armor	Improved design criteria for existing armor and established coefficients for new armor designs	$500,000 annually

Savings of Civil Works Research, 1977-1986 (Continued)

Problems Addressed	*Solution*	*Savings*
Research Area: Flood Control and Navigation		
Program: Flood-Control Hydraulics		
Inadequate state-of-the-art hydraulic design guidance and procedures	Developed and disseminated design guidance in several formats: Hydraulic Design Criteria (HDC), engineer manuals, engineer technical letters, computer programs for the computer-aided design system CORPS, and miscellaneous papers	$1,250,000 annually
Inadequate guidance for designating stable flood-control channels	Developed guidance concerning the applicability and limitations of channel improvement methods and analysis techniques	5% of project cost
Inadequate riprap design guidance	Developed practical riprap design using known or easily calculated variables. Determined stability of a wide range of riprap gradations and thicknesses	$300,000 annually
Unavailability of a design procedure for spillway crests applicable to a wide range of heads, approach depths, and upstream slopes	Developed design guidance for spillway crests including discharge coefficients, crest pressures, and water-surface profiles. Data provided for crests with and without piers for a wide range of conditions	$75,000 annually/ project
Abrasion at outlet works stilling basins caused by low flood eddies	Developed improved design guidance which adds inverted "V" downstream from outlet on trajectory	$150,000 annually
Unavailability of necessary data to use prototype testing of hydraulic structures to improve design guidance and to solve operational problems	Incorporated instrumentation capabilities in selected Corps projects to acquire needed data	$200,000 annually
Nonexistent hydraulic design guidance for selective withdrawal intake structures to satisfy flood-control project objectives in an environmentally compatible manner	Developed a numerical simulation tool which can be used to determine optimal number and elevation of multilevel intakes	$400,000 annually

Savings of Civil Works Research, 1977-1986 (Continued)

Problems Addressed	*Solution*	*Savings*
Program: Navigation Hydraulics		
No knowledge of the amount of air to introduce downstream of filling and emptying valves to prevent erosion or cavitation of lock culverts	Developed design guidance for lock culvert valve ventilation system	$25,000 annually
Inadequate design criteria for locks	Developed design criteria which eliminated the necessity of modeling each low-lift lock	$220,000 annually
Inadequate guidance for bendway channel width relationships in inland waterways	Developed specific design guidance for channel width with varying velocity, bend radius, distance between banks, and tow size	$3,700,000 annually
Lack of simulation techniques to aid in the design of deep- and shallow-draft waterways and harbors	Developed a ship-tow simulator to provide guidance for the determination of channel and harbor dimensions for deep- and shallow-draft navigation projects including elimination of existing hazards to navigation	$4,000,000 annually
Program: Hydrology of Cold Regions		
Inadequate guidance on sediment transport and bank erosion processes in cold regions	Provided guidance and assistance on sediment transport and bank erosion to Alaska District for groin placement for flood prevention	$250,000 annually
Inadequate guidance on the effects of permafrost on bank erosion	Provided guidance and assistance on the effects of permafrost or frozen ground on bank erosion to Alaska, St. Paul, and Rock Island Districts	$300,000 annually
Inadequate guidance on the nature of glacierized river basins	Provided guidance on nature of glacierized river basins to Alaska District	$75,000 annually
Inadequate instrumentation for monitoring snow water equivalent soil moisture and winter flows	Provided guidance and assistance on methodology or techniques for winter measurements and observations to various Districts and Divisions	$300,000 annually
Inadequate computer models for predicting runoff and routing for cold regions	Improved Corps model capabilities by modifying run-and-routing forecast models to account for cold regions effects	$200,000 annually

Savings of Civil Works Research, 1977-1986 (Continued)

Problems Addressed	*Solution*	*Savings*
Program: Ice Engineering		
Floating brash ice entering lock chambers	Developed a high flow air bubbler system to deflect floating ice out of the lock approach	$75,000 annually/ lock
Uplifting ice forces acting on marine structures	Developed a plastic jacket which effectively reduces uplifting forces	$50,000 annually
Downstream ice jam flooding resulting from rapid, peak power water releases	Installed bubbler system to move warm water to intakes to decrease the formation of ice	$75,000 annually
Inadequate ice boom design and performance	Developed design guidance for improving ice boom designs	$4,403,000 annually at seven sites where ice booms have been installed
Research Area: Environmental Quality		
Program: Environmental Impact		
Effects of beach nourishment on shore-zone animals	Developed assessment strategies and field study procedures	$300,000 annually
Compaction caused by beach nourishment	Demonstrated effectiveness of tilling to reduce compaction	$250,000/project
Inadequate guidance for revegetating construction sites	Prepared and demonstrated procedures for improving planting techniques	$2,500,000
Inadequate management for wildlife resources	Prepared manual of improved management techniques	$30,000 annually

Intangible Benefits Realized

Intangible benefits include reduced costs for preparing impact assessments and for monitoring projects, improved project operation, and enhanced realization of project benefits.

Program: Wetlands		
Inadequate preliminary guidance to Corps field inspectors on wetland types in their region	Produced eight preliminary regional guides that describe wetland types and dominant species in each	$300,000 annually
Inadequate procedures for identifying and delineating wetlands subject to Section 404 of the Clean Water Act	Developed multiparameter approach, providing a method for achieving standardized wetland determinations throughout the nation. Documented the approach in a "Wetlands Delineation Manual"	$800,000 annually
Unavailability of a standard procedure for assessing wetlands functions and values	Adopted, modified, improved, and computerized a method developed by the Federal Highway Administration	$2,000,000 annually

Savings of Civil Works Research, 1977-1986 (Continued)

Problems Addressed	*Solution*	*Savings*
	Program: Wetlands	
Unavailability of a wetlands functions and values database	Cooperated with US Fish and Wildlife Service in developing a wetlands functions and values database. The database contains more than 5,000 technical articles	$1,100,000 annually

Research Area: Water Resources Planning Studies

Program: Planning Methodologies

Unavailability of methods to identify regional economic impact of water resources projects	Developed regional economic assessment computer models for navigation planning studies	$5,000,000
Lack of techniques which incorporate nonstructural measures into the flood mitigation planning process	Developed nonstructural alternatives to traditional flood-control methods	$9,500,000
Lack of methods for assessing employment opportunities associated with the construction of Civil Works projects	Developed procedures for measuring employment opportunities for Corps construction projects	$15,000,000
Unavailability of procedures and models for assessing the benefits of including recreation facilities at Corps projects	Prepared a manual for evaluating recreation opportunities at Corps projects	$8,600,000

Intangible Benefits Realized

Intangible benefits include integration of social considerations into the planning process as required by law and regulation, and reduced adverse social consequences of construction activity.

Program: Analytical Techniques

Lack of documented flood emergency planning methods for Federal and non-Federal dam safety	Developed guidance for preparing flood emergency plans for evacuation of downstream communities	Intangible—mostly increased capabilities to respond to emergency operations
Lack of automation for flooding, flood routing, hydrologic, hydrodynamic, reservoir operation, and other flood damage reduction measures	Developed over 70 computer programs to respond to various water resources related inquiries and emergencies	Intangible

Intangible Benefits Realized

Intangible benefits include provision of more efficient use of manpower and computational resources, and provision of improved, more economical, and faster analyses.

Savings of Civil Works Research, 1977-1986 (Continued)

Problems Addressed	*Solution*	*Savings*
Program: Water Supply and Conservation		
Lack of evaluation techniques and procedures to enable Corps planners to incorporate water conservation features into water supply planning, engineering, and design	Developed procedures manuals, handbooks, and technical reports on drought management measures; determined the effect of price on water demand; and determined the long-term effects of conservation measures. All of these are now used by the Corps and others involved in water supply and conservation planning	$2,800,000
Lack of a modern disaggregated water demand forecasting model to provide accurate estimates of future water supply needs	Developed a state-of-the-art water demand forecasting model, IWR-MAIN, and adapted model to provide the Corps with the capability to make accurate water needs assessments. A mainframe and personal computer version of the model are available	$3,600,000
Lack of methods and models to plan and design water supply systems incorporating ground-water models and conjunctive use measures	Developed ground-water models and conjunctive use planning framework which describe the economic and institutional aspects of surface—ground-water systems	$1,700,000
Lack of technical and cost optimization tools for water supply system planning maintenance and rehabilitation	Developed and adapted models which allow planners to determine least cost alternative water system design and to stage the development of water supply systems	$2,800,000

Intangible Benefits Realized

Intangible benefits include manpower savings from computational efficiencies and savings to the nation in the form of reduced resource requirements to meet the water demand of the future.

Program: Risk Analysis		
Lack of risk analysis methods for dam spillways consistent with current policy on retrofit of hydrologically deficient dams	Made available the specific analytical techniques, models, and reports of case studies to Corps personnel engaged in rehabilitation problems	$100,000/application

Savings of Civil Works Research, 1977-1986 (Continued)

Problems Addressed	*Solution*	*Savings*
Research Area: Surveying and Satellite Applications		
Program: Surveying and Mapping		
Unavailability of effective and efficient hydrographic surveying methods	Developed cost-effective and efficient hydrographic surveying methods	$12,000,000
Unavailability of highly accurate topographic surveying methods	Developed airborne laser topographic surveying method; the global positioning system has been tested and has proved feasible for various surveying applications	$1,500,000 annually
Program: Remote Sensing		
Unavailability of techniques for using satellite data to prepare land cover maps	Developed techniques for preparing land cover maps using Landsat multispectral scanner data	$20,000/application
Unavailability of instrumentation for making real time water resources management decisions	Developed and tested sensors to obtain hydrometeorological data in near real time	$1,000,000 annually
Inability to monitor economically shoreline erosion resulting for reservoir and locks and dams operation	Developed conventional photo-interpretation and digital image processing techniques to monitor shoreline recession rates	$500,000 annually
Lack of snowmelt runoff data	Developed procedures for using airborne and satellite instrumentation to obtain spatially distributed snow, rainfall, and soil moisture data	$1,000,000 annually
Inability to economically monitor deep-draft channels and deepwater dredged material disposal areas	Implemented multiple electronic positioning and hydrographic survey systems to measure channel geometries and to ensure accurate placement of dredged material	$1,000,000 annually
Inability to define accurately the extent of flooding during emergency operations	Developed techniques for using National Oceanic and Atmospheric Administration satellite imagery instead of using conventional data collection for producing flood location maps	$50,000 annually
Research Area: Construction, Operation, and Maintenance		
Program: Operation and Maintenance Management		
Lack of reliable means of providing accurate cost estimates	Developed a computer program for updating and tracking estimates in process	$45,000/application

Savings of Civil Works Research, 1977-1986 (Concluded)

Problems Addressed	*Solution*	*Savings*
Program: Improvement of Operation and Maintenance Techniques		
Lack of accurate and reliable methods for predicting channel dredging requirements	Developed computer model, TABS-2, for predicting and evaluating channel shoaling rates	$3,500,000 annually
Lack of criteria and design guidance for reducing maintenance dredging costs	Developed advance maintenance dredging procedures which will reduce maintenance dredging costs	$200,000 annually
Lack of methods for predicting scour around coastal structures during construction	Developed stability design guidance for underlayer material placement	$100,000 annually
Lack of evaluation of replacement of steel dredge pipe with plastic pipe	Completed evaluation of high density polyethylene (HDPE) pipe	HDPE is estimated to be four times more wear resistant than steel pipe; monetary savings are still being determined
Program: Long-Term Effects of Dredging Operations (LEDO)		
Need for improving and prolonging the life of existing dredged material disposal areas	**Developed design guidance for measuring the capacity of existing dredged material disposal areas**	$350,000,000
Lack of design criteria and guidelines for disposing of dredged material in open waters	Developed technology which allowed open-water disposal alternatives	$30,000,000
Lack of an estimate of actual/potential toxic substances bioaccumulation and biomagnification from dredged material sediments in aquatic organisms	Developed simple laboratory test methods to predict toxic substances in aquatic organisms	$9,000,000
Lack of field tests and evaluative methods for assessing the environmental effects of dredged material	Developed field tests and predictive methods for accurately and precisely assessing environmental effects of dredged material on aquatic, wetland, and upland habitats	$1,000,000 annually
Program: Natural Resources		
Lack of improved methods for planning, designing, and managing recreation and material resources	Developed guidelines and methodologies for improving campsite, campground design, sanitary facilities, visitor safety and security, and visitor accommodation	Benefits to date have been mostly intangible; $1,000,000 annually

Part III
RESEARCH AREAS AND PROGRAMS

This section presents a more detailed view of the type and diversity of the Corps of Engineers' Civil Works research activities and accomplishments. It will not only elaborate on the work and benefits presented in the preceding section but will also summarize recent accomplishments of each Program without regard to evaluation of its economic significance.

Materials

Soils

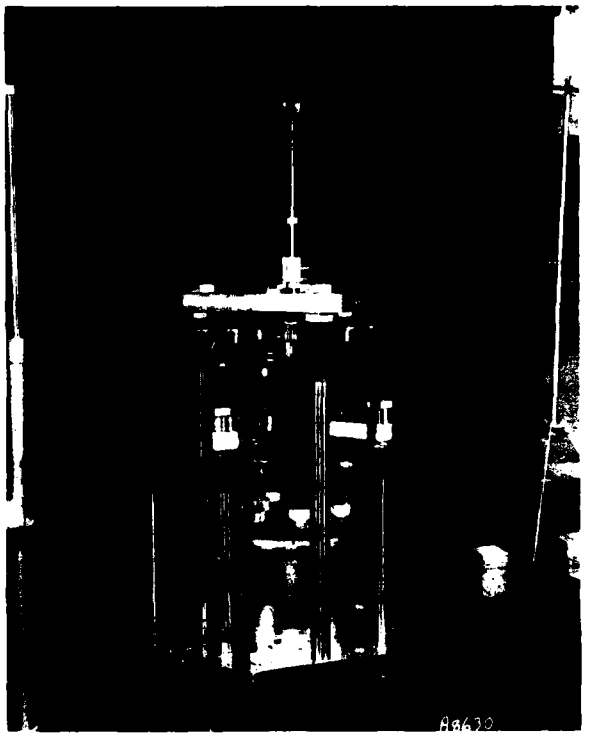
Based on Civil Works R&D, assistance related to problems encountered with dispersive clay, granular and geotextile filters, earth-rock mixtures, cracking of embankments, instrumentation, compaction control, planning and conducting seismic stability analyses of dams, design of embankments for overtopping, in situ testing, and pile foundations was provided to various offices. Significant accomplishments were:

1. Methods for obtaining maximum/minimum density of large-particle soils using 18- and 36-in. molds were developed.
2. A theoretical model for shear band formation was formulated and validated.
3. A small-scale test apparatus was designed and fabricated for measuring the performance by similitude of in situ testing devices (one-fourth and one-half scale); a contract report, "Field Evaluation of SPT Energy, Equipment, and Methods in Japan Compared with the SPT in the United States," concluded a cooperative study with the US Bureau of Standards.
4. Under cooperative support by the Corps and others, the National Academy of Science Committee on Earthquake Engineering prepared a workshop report, "Liquefaction of Soils During Earthquakes," to be used as a primary reference for forthcoming regional seminars, "Hazard at Saturated Soil Sites: Evaluation and Mitigation."

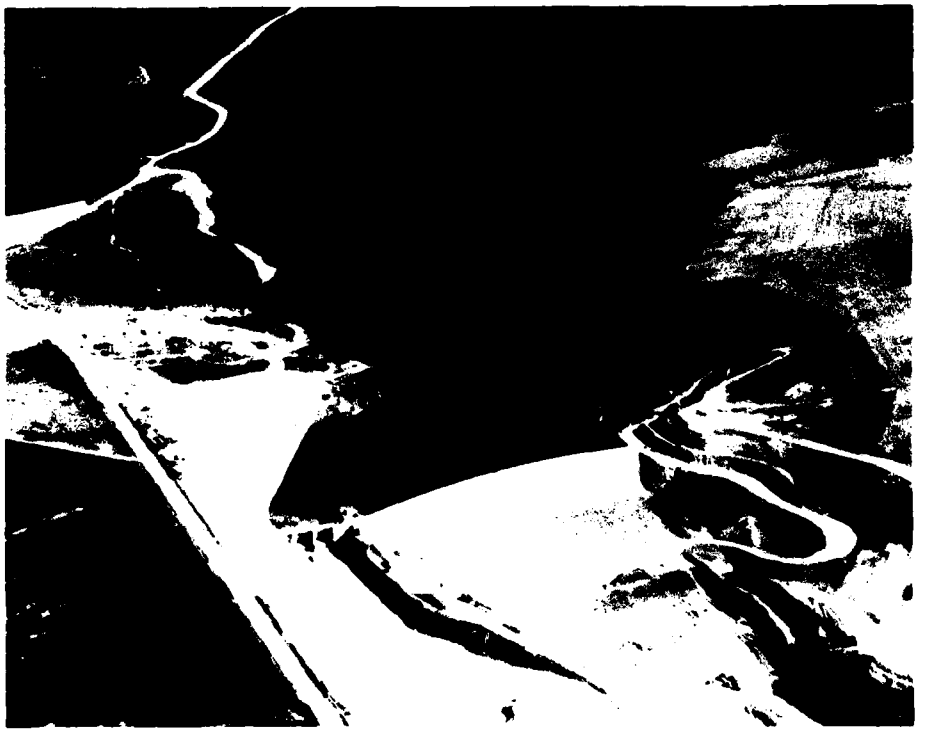
Rock

This research encompasses interdisciplinary efforts involving geology, seismology, geophysics, rock mechanics, and foundation and structural engineering. The design and the economical and safe construction of major Corps structures, and the assessment of existing Corps structures for structural integrity are dependent upon a thorough knowledge of the before-mentioned disciplines. Such considerations necessitate methodologies for designing structures for local flood protection and floodplain management, waste treatment facilities, flood control, and navigation.

Through research, improved and standardized methodologies have been and continue to be developed for the field agencies. Assistance provided for the Fort Peck Dam, Dickey-Lincoln School, Richard B. Russell Dam, Barkley Dam, Ririe



Small-scale penetration apparatus.



Ririe Dam.

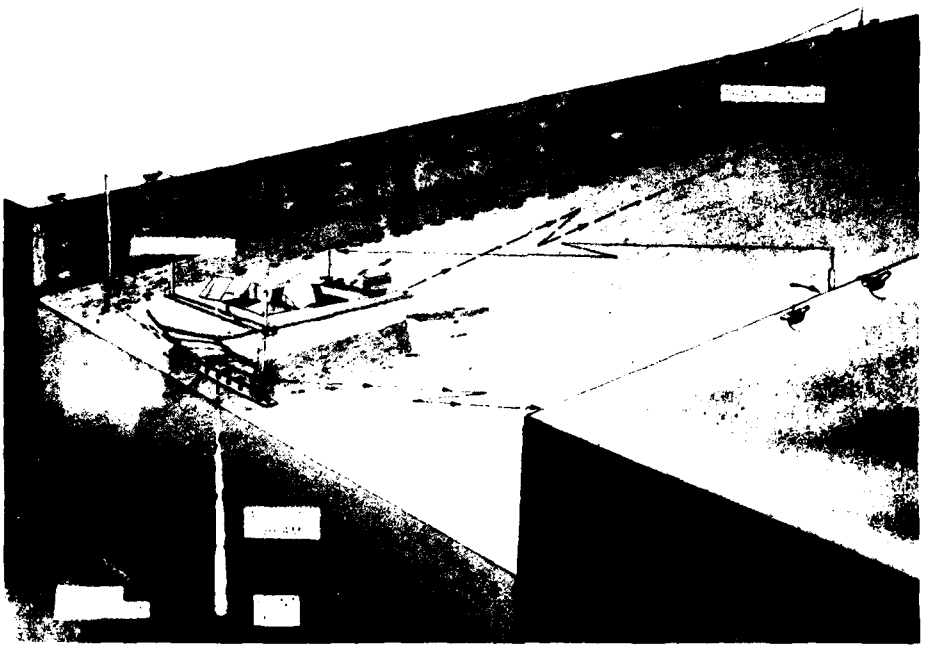
Dam, and Patoka Dam projects are excellent examples where research has contributed significantly to the successful construction of Corps projects.

Concrete

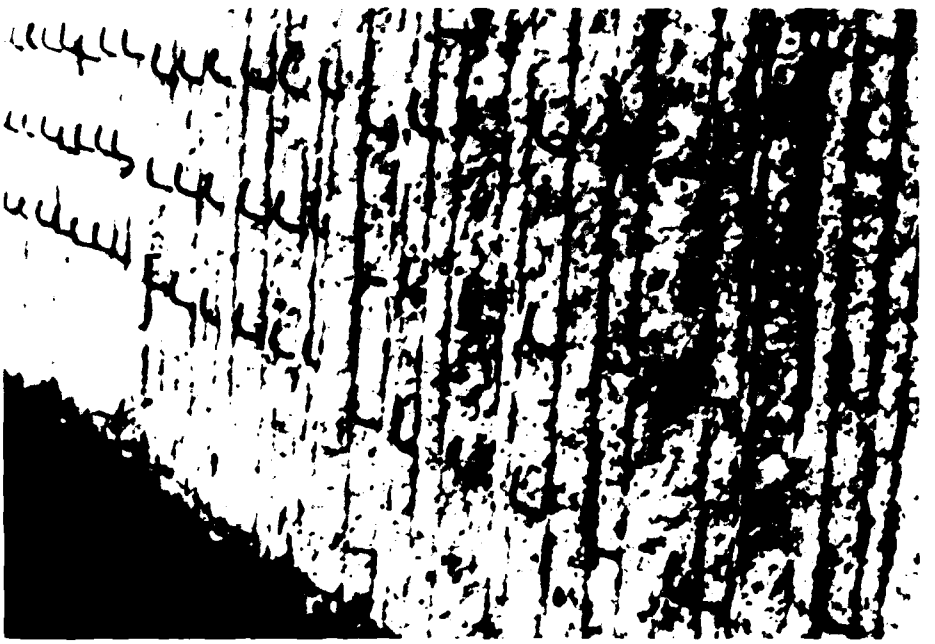
Concrete research primarily focuses on the development and evaluation of new technologies for making, placing, and testing concrete and includes: (1) evaluation of various types of concretes containing numerous admixtures following exposure to severe ambient conditions at mean-tide level at Treat Island, Maine; (2) evaluation of cracking phenomenon of massive concrete structures and establishing standards and construction practices which should minimize such occurrences; (3) evaluation of various cementitious materials other than portland cement so that acceptable specifications can be established for their use; (4) evaluation of the alkali-silica reaction potential of various aggregates which were previously considered nonreactive; (5) evaluation of current specifications for curing compounds to determine if the stricter Corps of Engineers requirements are necessary and economically acceptable; and (6) evaluation of a high-resolution acoustic mapping system for assessing underwater structures without dewatering the projects.

Usable products generated as a direct result of this program have been many and varied. A partial listing of recent significant accomplishments includes: (1) revision of the *Handbook for Concrete and Cement*; (2) evaluation of high-range water-reducing admixtures for concrete construction; (3) evaluation of the Rapid Analysis Machine (RAM) for rapidly determining cement content of freshly mixed concrete; (4) evaluation of roller-compacted concrete testing and construction techniques; (5) evaluation of techniques and materials currently

Cracking of concrete structures.



High-resolution acoustic mapping system.

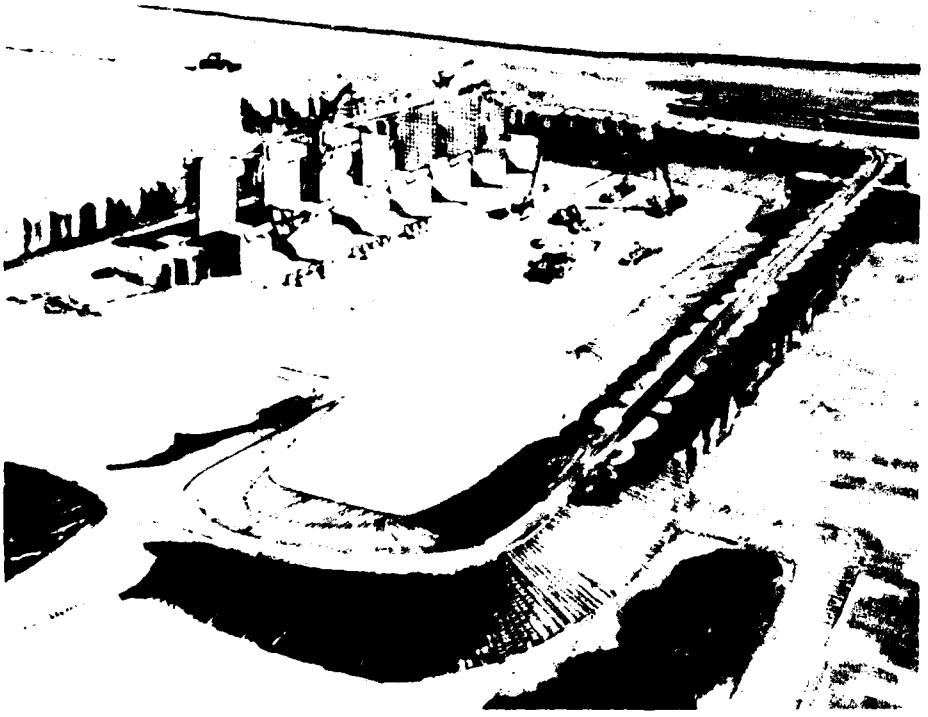


Repair and rehabilitation of erosion-damaged hydraulic structures.

being used in the repair and rehabilitation of erosion-damaged structures; and (6) the continuing evaluation of alkali-silica reactions with certain types of aggregates.

Structural engineering

This program has produced many results which have been quickly put to practical application by District and Division Offices. Foremost among these products is a growing collection of user-friendly computer programs to analyze or design common types of hydraulic structures. Other notable achievements are simple procedures for seismic analysis which incorporate the effects of the most significant dynamic variables. Interim strength design criteria suitable for the peculiar problems of Corps hydraulic structures have also been developed under this program.



Lock and Dam 26 (replacement) design of cellular cofferdam, group pile foundation, and tainter gates. Three-dimensional stability analysis done using Computer-Aided Structural Engineering techniques.

The Computer-Aided Structural Engineering projects have generated over 39 computer programs for field use. The Soil-Structures Interaction Studies program has provided guidance for developing analytical and testing procedures for the design and analysis of hydraulic structures. Products from this work have resulted in four computer programs being released to the field.

Electrical/mechanical

This program provides improved design guidance for small hydraulic pumping station pumps, for paints and other high-performance protective coatings, and for mitigating the effects of corrosion at all Corps projects. Results from small pumping station research have been utilized by the Huntington, St. Louis, and Memphis Districts. The Department of the Army has signed an exclusive licensing agreement with an Ohio firm to manufacture and market the Corps-developed, plasma-sprayed ceramic anode which has proven to be less expensive and has a longer economic life than the solid niobium or tantalum anodes currently used.

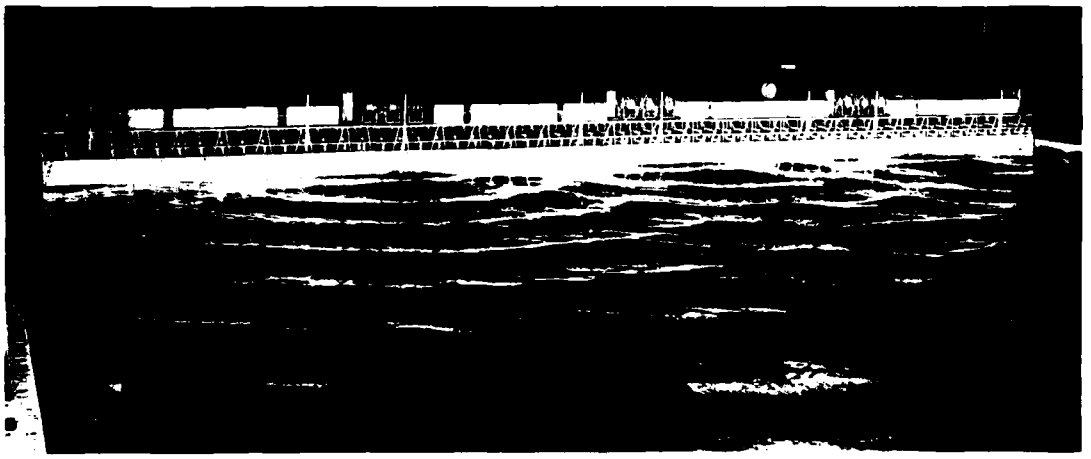
Coastal Engineering

Coastal flooding and storm protection

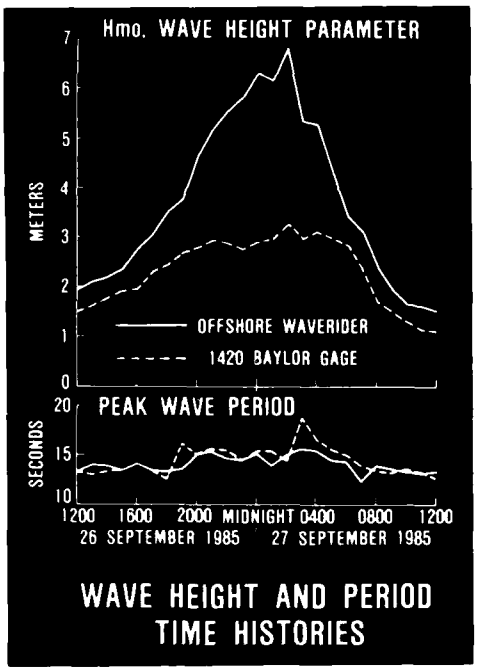
Research from this program includes theoretical and numerical studies, experimental laboratory and field investigations, and prototype data collection and analysis. This program has developed complex numerical models that predict water-level rises caused by hurricanes and other large storms, models that transmit storm surge from the open ocean through inlets into back bays, models that estimate the transformation of waves in shallow water, comprehensive data sets from the Field Research Facility and Hurricane Surge Data collection network, and improved laboratory simulation techniques.

Recent significant accomplishments include:

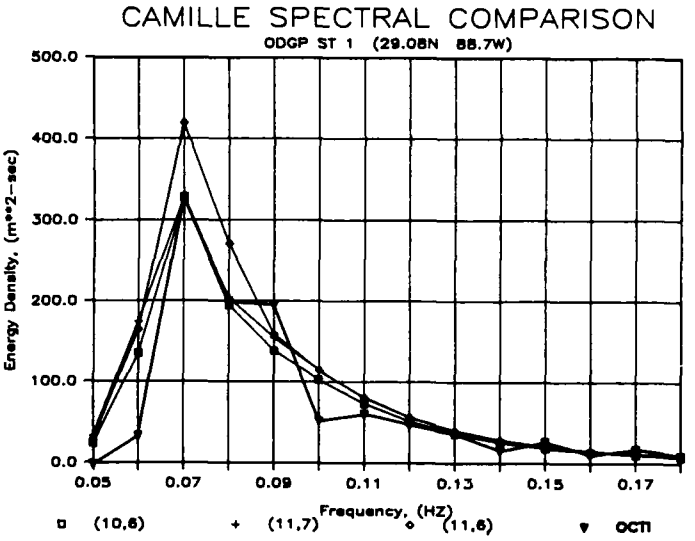
1. The spectral wave generator was completed and is now in operation.
2. With numerous participants from the academic community and foreign countries, experiments designed to measure nearshore coastal processes such as currents and sediment transport were conducted at the Field Research Facility in North Carolina in 1985 and 1986 including wave, current, and water-level measurements during Hurricane Gloria.



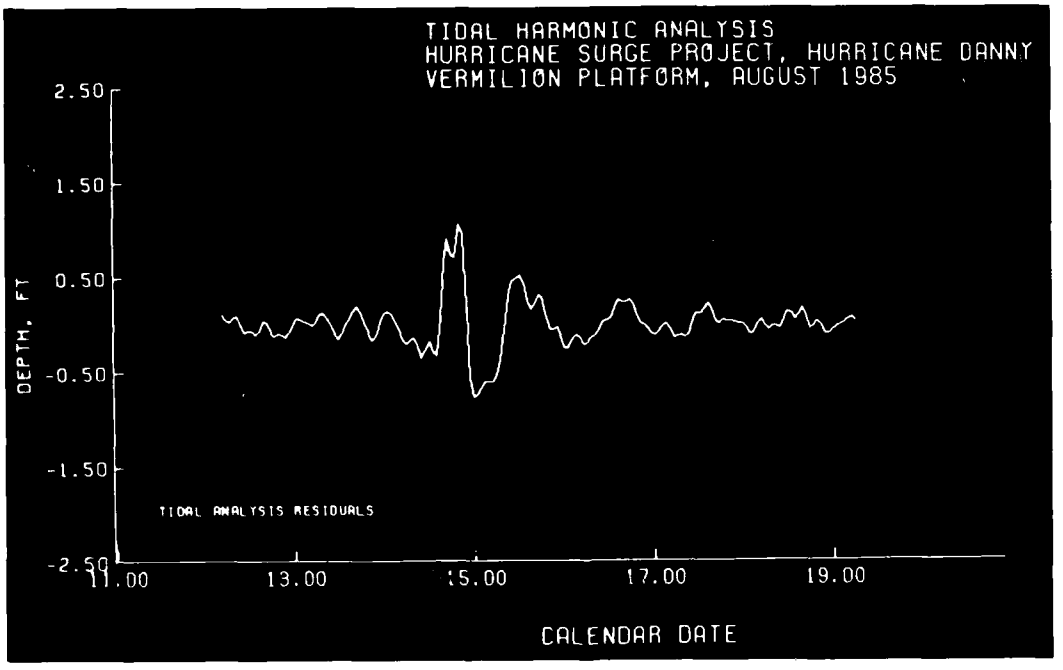
The directional spectral wave generator is now in operational use for both research and mission support studies.



Wave, current, and water-level measurement programs yielded a wealth of data including invaluable data during the passage of Hurricane Gloria.



A numerical model for predicting directional wave spectra in hurricanes has been developed and tested and is now in use in mission support studies.



Storm surge measurement programs gathered data in Hurricane Danny on the Louisiana coast.

3. For the first time, quantitative, time-dependent simulations of the hurricane forerunner can now be performed, and results of simulations for historical storms can be used to initialize regional storm surge models. Hurricane surge data were collected during several storms and a numerical model for computing hurricane waves developed.

Harbor entrances and coastal channels

This research includes theoretical and numerical studies, experimental laboratory and field investigations, and prototype data collection analysis. Currently, the majority of emphasis and resources is placed on theoretical and numerical investigations and data collection and analysis.

Shoaling of inlet bars is a continuing problem in the Corps' effort to maintain adequate navigation depths, and a better understanding of the physical processes responsible for this shoaling is basic to developing design criteria aimed at reducing costs of project maintenance. Literature on inlet shoaling rates and patterns and on techniques for predicting shoaling rates was evaluated. An in-depth report on the state of the art was prepared. Field data were collected at the Field Research Facility on sediment transport outside the breaker zone. No comprehensive source of information or guidance is available which describes planning and selection procedures for sand bypassing systems. Such systems, used to pass sand across tidal inlets or harbor entrances, rely primarily on intensive project development. Work on compiling a systematic approach to the design and selection of sand bypassing systems will reduce project costs

Removal of sand from harbor entrance channels remains a significant Corps problem. Guidance for development of sand bypassing systems is being readied for publication to provide the field with state-of-the-art methods to solve this problem.

Interaction of waves, currents, sediment, and structures at coastal entrance channels produces complex shoaling and scour problems, and dangerous navigation problems. Research is under way to develop a numerical model to predict wave and current patterns in these complex systems.

considerably. Initial steps in the work were completed, including a methodology for characterizing the problem, a description of the basic concepts of sand bypassing systems, and definition of data and data analysis requirements. Wave-current interactions at entrances to tidal inlets and harbors can produce dangerous conditions for both small crafts and ships attempting to navigate through these entrances. Wave-current interactions have a major influence on sedimentation in entrance channels and adjacent coastal areas. Development of a large grid mesh numerical model to study wave-current interactions is under way. A complementary two-dimensional numerical model for wave propagation at entrances was completed and a user's manual prepared. A comprehensive knowledge of the nearshore waves and currents in the vicinity of harbor entrances and coastal channels is basic to developing improved guidance to minimize channel shoaling. The lack of reliable and quantitative methods for the prediction of nearshore waves and currents was partially alleviated by completion of a literature review and state-of-the-art report on nearshore currents.

Results of this report were used to develop a preliminary numerical model for prediction of nearshore waves and currents. This technology was transferred to field personnel by means of a workshop. An extensive field experiment was held at the Field Research Facility in conjunction with investigators from the US Geological Survey and Oregon State University to collect quantitative current and wind stress data, which will be compared with model predictions.

Shore protection and restoration

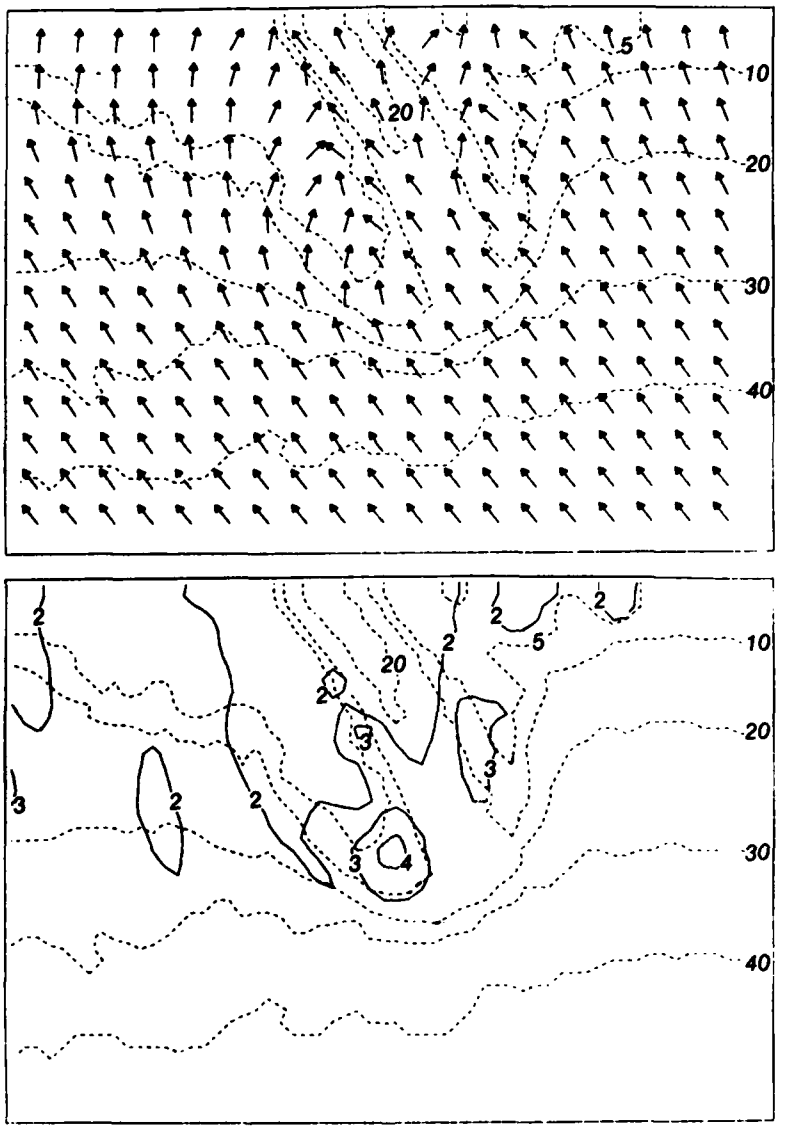
This research includes theoretical and numerical studies, experimental laboratory and field investigations, and prototype data collection and analysis. Currently, there is a balance of research with slightly more emphasis being placed on experimental field investigations and data collection and analysis.

A set of 16 historical (since 1850) shoreline change maps for the Delmarva Peninsula of Delaware, Maryland, and Virginia was published under a cooperative agreement with the National Oceanic and Atmospheric Administration, National Ocean Survey. A major field collection effort involving surface and subsurface sediment samples and bottom profiling was conducted at Ocean City/Assateague, Maryland, to study barrier island evolution in the presence of navigation structures. Historical shoreline change analyses were also conducted. A field study of sediment transport characteristics and the geomorphic history of

Research on barrier island systems continues with development of shoreline change maps, collection of geologic data, and analysis of barrier island response to structures.

Isles Dernieres, Louisiana, was conducted. The engineering implications of sea level rise were investigated through participation with the Marine Board, National Research Council.

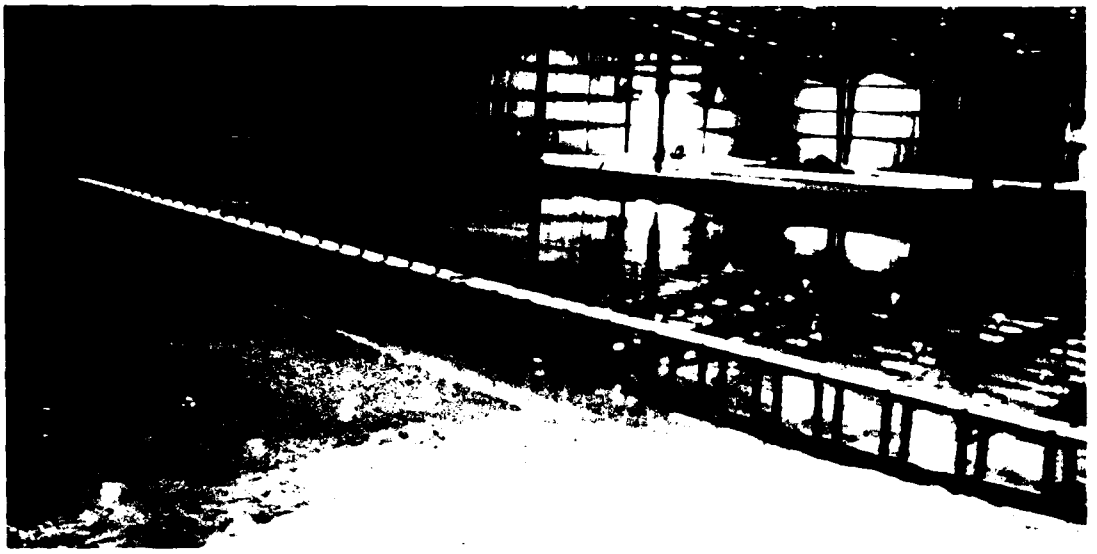
A report was published documenting a wave propagation model that determines combined refraction-diffraction of waves over a complex bathymetry. The model was transferred to District offices through a workshop and was used in



LEGEND

——— WAVE HEIGHT CONTOURS ARE IN FEET
- - - - - DEPTH CONTOURS ARE IN FEET
←——— WAVE DIRECTION

A refraction-diffraction model is required to make accurate estimates of wave conditions in complex beach areas. This model has been transferred to District offices for use.



The beach region near the Field Research Facility is being simulated in a movable-bed model. The accuracy with which real events can be reproduced in the model provides information on the scaling laws and techniques used.

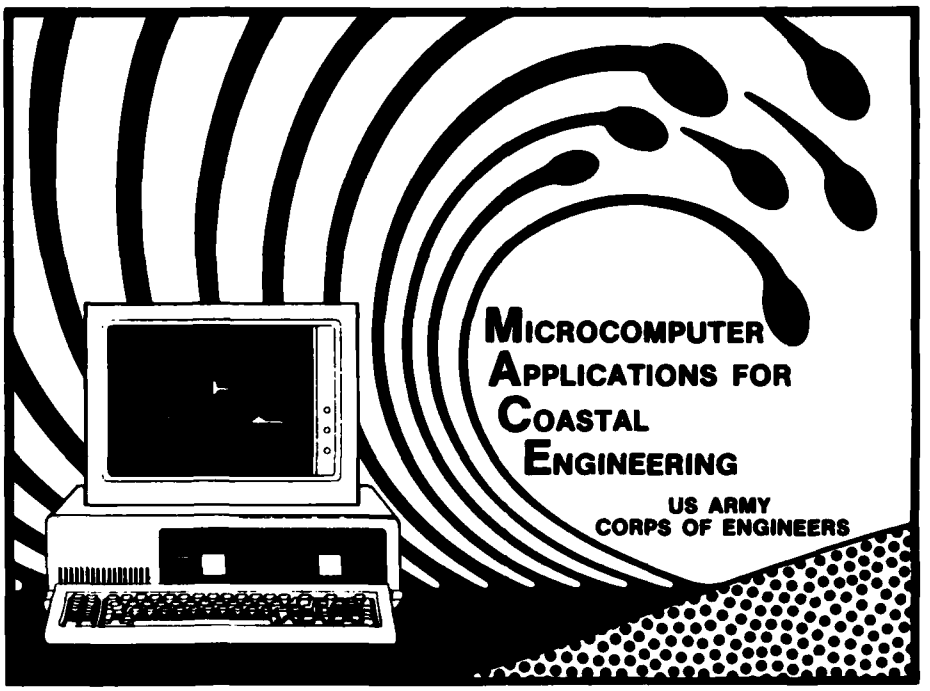
several District studies. A shoreline response numerical model developed in Japan was tested and its capabilities expanded by adding the ability to consider sea walls. Postfill conditions at Delray, Florida, were monitored to assess whether compaction contributes to apparent losses of fill material. A user's manual for the Interactive Survey Reduction Program and a report describing use of a Dutch technique for estimating dune erosion were published. Technical reports were completed on sand transport distribution over weir jetties, statistics of energy flux, and visual wave observations.

Research continues in the development of improved methods to model sediment transport in the laboratory. Extensive data sets collected at the Field Research Facility are being used to verify a movable-bed model. Development of this technology will allow more accurate prediction of many problems involving shoaling or scour and erosion.

Coastal structure evaluation and design

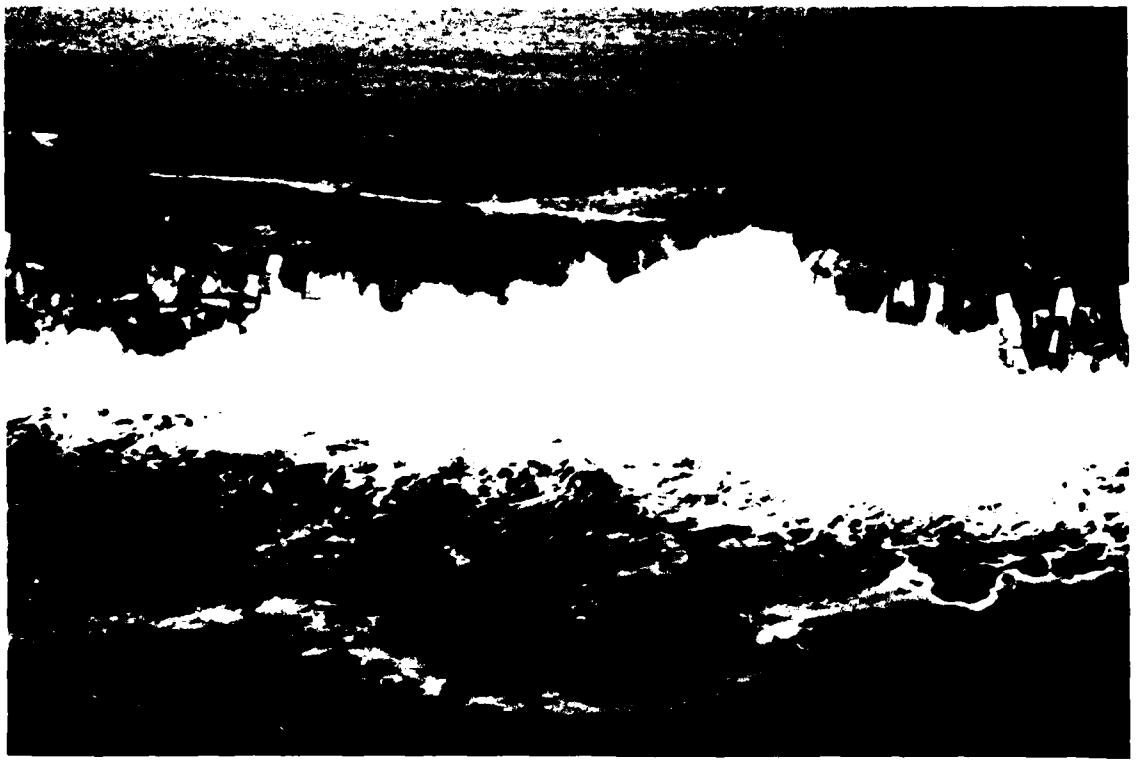
This research includes experimental laboratory and field investigations and prototype project performance monitoring. This research program provides the funding for some of the major technology transfer mechanisms in the entire Coastal Engineering area.

Nine microcomputer programs were completed for Microcomputer Applications for Coastal Engineering. Documentation was published in a technical report and in Coastal Engineering Technical Notes (CETNs). Contracts were initiated for assistance in preparing Microcomputer Applications for Coastal Engineering, and three people were employed under Intergovernmental Personnel Act (IPA) appointments. A total of 18 CETNs were published. A technical report, "Cost Effective Optimization of Rubble-Mound Breakwater Cross Sections," was



Design formulae and simpler methods have been incorporated into a series of microcomputer programs that are distributed to District offices. Not only do these programs decrease man-hours required to complete designs, the results are also more accurate because nomograms are replaced with explicit equations.

completed. Work continued on two instruction reports. These instruction reports are more detailed than other reports and can stand alone as authoritative texts on their subjects. An improved method was developed to calculate overtopping rates for naturally occurring storm wave conditions. A draft technical report, "Review and Comparison of Methods for Estimating Irregular Wave Overtopping Rates," was prepared. A final draft of the engineer manual, "Design of Breakwaters and Jetties," was prepared. Tests were completed and a draft report was prepared on percent damage and wave transmission heights for dolosse and stone-armored breakwater trunks using waves greater than the design wave height. Trunk tests continued on breakwater heads and angular wave attack on breakwater trunks, and tests were initiated using spectral waves. A simple relation for defining initiation of armor stone movement of overtopped rubble mound structures was developed. Comprehensive models were developed for reef breakwaters to predict stability, wave transmission, wave reflection, and energy dissipation, and a draft technical report was prepared. Tests were initiated for riprap stability using a minimum layer thickness on 1:1.5 slopes. The Floating Tire Breakwater Workshop was held at Niagara Falls, New York. A draft report on the Floating Breakwater Prototype Test Program was completed, and a draft engineer technical letter was prepared. Data analysis continued and the comparison, verification, and calibration of existing numerical models was initiated. A floating tire breakwater monitoring effort was performed at Pickering Beach,



Wave attack research on breakwaters emphasizes overtopping and transmission of irregular waves typical of design storm events.

Breakwater heads are often the portion of the breakwater most vulnerable to damage. Studies continue of methods to improve the design of these elements by initiating tests with irregular wave conditions. The photograph shows damage after a head-on wave attack.

Floating breakwaters can offer cost-effective wave protection in areas with short-period waves. Detailed information gathered during the Corps' major field data collection effort is now being used to provide design guidance and to verify models of the structures.

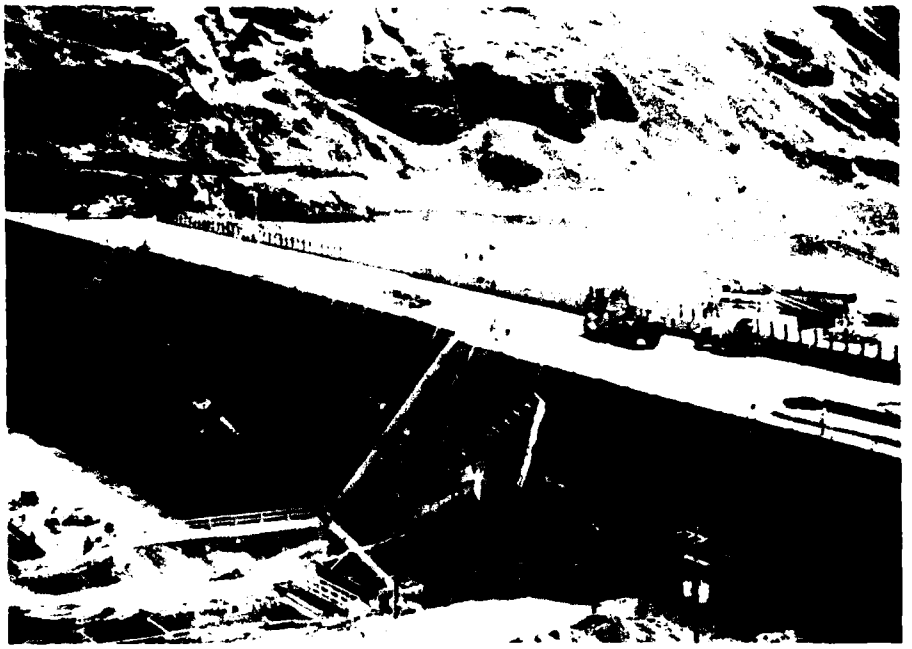
Delaware. Draft reports were prepared on design of detached breakwaters for shore protection and comparisons of coastal survey techniques. Cooperative monitoring and evaluation continued on detached breakwaters at Lakeview Park and Lakeshore Park, Ohio, and Colonial Beach, Virginia, and on jetties at Murrells Inlet and Little River Inlet, South Carolina. Research continued on the application of airborne laser mapping techniques, and a report was prepared on an application of side-scan sonar technology.

Flood Control and Navigation

Flood-control hydraulics

This research program develops and disseminates timely guidance for solution of priority mission problems in the area of flood control. Currently, the field indicates a high-priority need for research and prototype studies to develop improved guidance for cost-effective design, construction, rehabilitation, operation, and maintenance of flood-control channels and structures. This information and technology is vital to the accomplishment of the overall national objective of obtaining maximum multipurpose use of our water resources. Recent accomplishments in this program are summarized below.

A major revision (18th Issue) of Hydraulic Design Criteria has been completed and is undergoing internal review. The revision includes material related to spillway design using the approved elliptical shape including crest shape, discharge coefficients, pier contraction coefficients, water-surface profiles, crest pressures, and cavitation safety curves. Guidance for design of two-way drop inlet



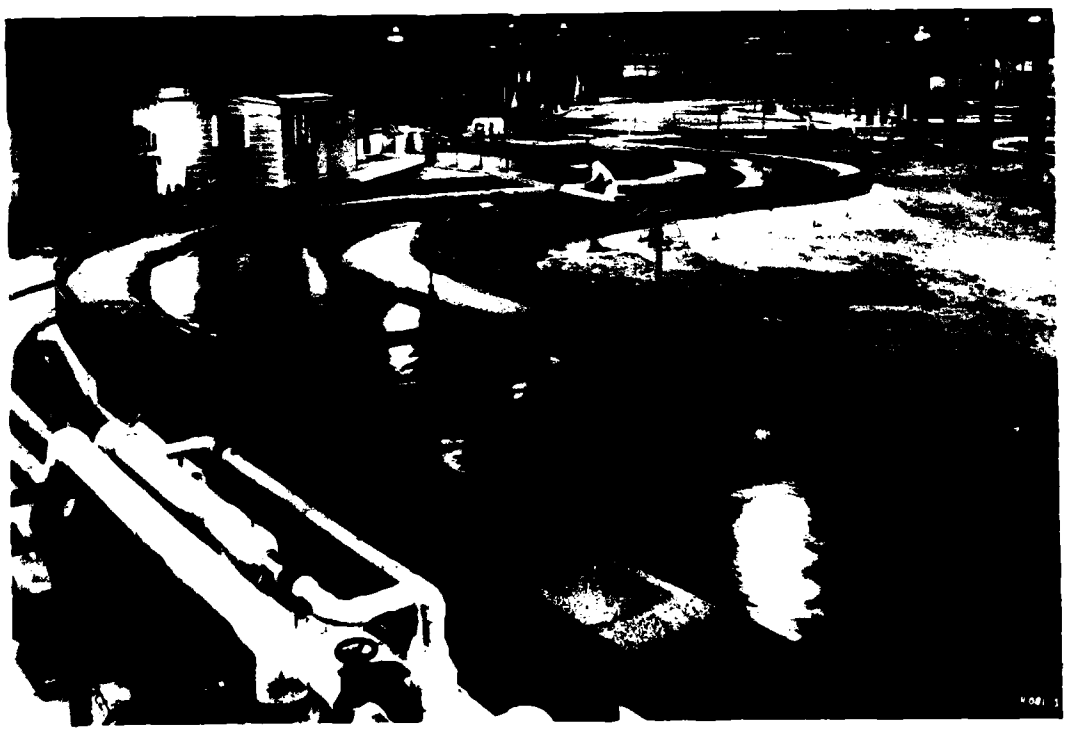
Computer-aided design procedures for hydraulic structures.

structures and drop intake structures is included along with revisions to several other Hydraulic Design Criteria charts. Corps computer programs associated with some of these topics have also been developed and documented. A draft of a miscellaneous paper comparing four methodologies for riprap design was completed along with a proposed computer program which will assist with riprap design. A draft revision of the engineer manual on hydraulic design of navigation locks has been completed.

Recent projects reflect a major emphasis on small, local-cooperation flood-control projects. Under this research effort, data pertaining to channel improvements and stabilization measures for various types of streams encountered in the Corps of Engineers' flood protection projects are being collected. These data are being analyzed, correlated, and used to help develop technical guidance. Initial work was directed toward developing Hydraulic Design Criteria providing guidance for making a qualitative analysis, for defining data requirements for project analysis, and for planning and analyzing selective clearing and snagging improvement projects. Corps computer programs to help in predicting flow resistance and river regime have also been developed. A nationwide inventory of flood-control channel projects was conducted to develop information which will help define guidance and select projects which may be analyzed to determine the effectiveness of various channel improvement methods.

Improved guidance concerning riprap protection is urgently needed to reduce the high annual maintenance and repair costs experienced by field offices. Physical model investigations are being used to determine the basic flow mechanics of controlling parameters. Tests to determine the effects of gradation

Research is under way to develop improved design guidance for small flood-control projects such as Little Blue River, Kansas.



Channel bank riprap tests in curved channel test facility at WES.

on riprap stability in straight channels have been completed in existing small-scale facilities, and interim results have been summarized in a draft report and presented in training courses related to hydraulic design of flood-control channels. Additional tests in the small-scale facility are investigating riprap stability in curved channels. However, since larger test facilities are needed to study riprap at rock sizes more representative of the prototype, a larger riprap test facility is under construction and will be completed and in operation in the near future.

In the interim, because of the urgency of the need for improved guidance, other research avenues are being pursued. Colorado State University completed a third series of tests addressing the effects of riprap blanket thickness on stability. A draft technical report has been prepared summarizing the results of the three series of tests at the University.

A continuing effort is being made to plan for and/or conduct prototype tests which will provide data and information needed for the development of improved design and operational guidance. Field testing of some hydraulic phenomena is required since the phenomena cannot be adequately treated analytically nor can they be accurately scaled in the laboratory. In these cases, the field data are used to confirm model or analytical predictions or to provide information which cannot be otherwise obtained. A continuing review of proposed new structures is made to identify projects where future tests could provide such data. During FY 85, prototype tests were conducted at Bay Springs Lock, Mississippi; Bloomington Dam, Maryland; Chief Joseph Dam, Washington; Garrison Dam, North Dakota; and St. Stephens Powerhouse, South Carolina. Plans and specifications were prepared for the Crater Lake, Arkansas, powerhouse tunnel instrumentation and

Prototype tests to confirm performance and to ensure safe operating conditions for fixed-cone valves at New Melones Dam, California.

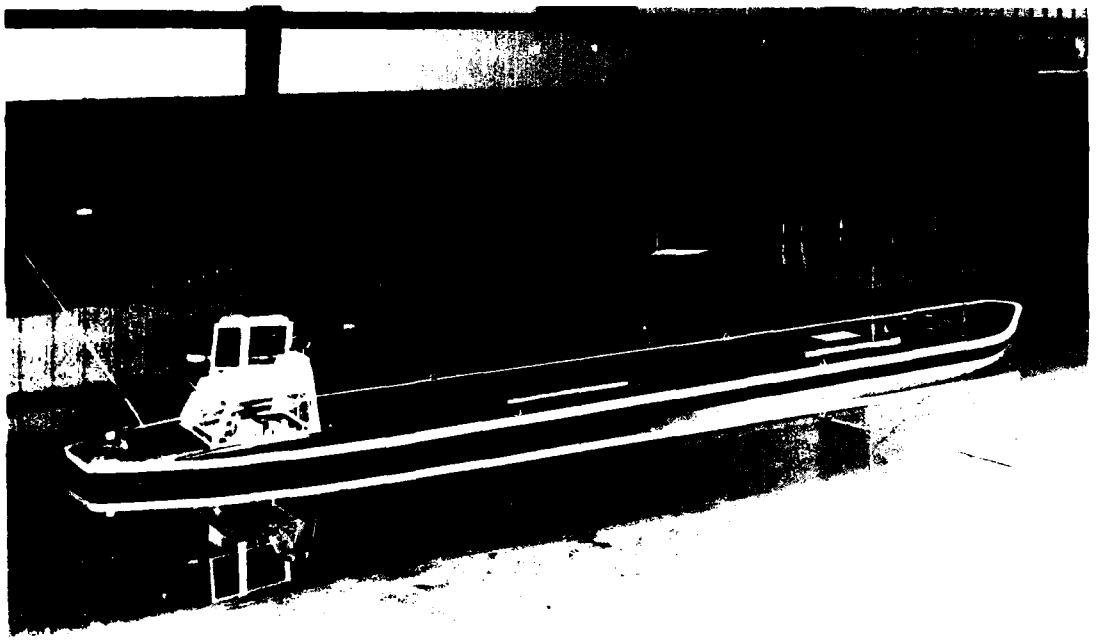
the Summersville Dam, West Virginia, valve hood modifications. FY 86 tests are anticipated at Stillhouse Hollow Dam, Texas; Gillham Dam, Arkansas; Taylorsville Dam, Kentucky; and Warm Springs Dam, California. All of these tests provide valuable design or operational guidance not otherwise obtainable.

Both flood-control and navigation projects include channel stability and maintenance in their design. These are related to cross-section shape, channel alignment, and stream profile slope, but no systematic method exists for calculating the proper width of channel to convey a prescribed hydrograph of water/sediment. Work was initiated in FY 84 to provide a systematic way for establishing channel width. The work involves analysis of various proposed techniques to determine which one is best supported by field data. Results of this work will be implemented in Corps of Engineers design procedures for field use and will significantly improve numerical sediment transport modeling. Techniques have been identified for evaluation and field data sets accumulated for the tests.

Navigation hydraulics

This program combined research being conducted for navigation locks and dams and channels to provide improved criteria and procedures for design, construction, operation, maintenance, and rehabilitation of various types of navigation locks and channels associated with multipurpose navigation projects.

A channel dimension and alignment study was completed, and results were included in the "Deep-Draft Channel" engineer manual. Research is continuing on the effects of bends on deep-draft navigation dimensions; the results are expected to be available for inclusion in the "Deep-Draft Channel" engineer



Radio-controlled scale model tanker used for deep-draft navigation dimension test (scale of 1:100).

Test reach on Hydraulic Design of River Training Structures. Present tests are concerned with spacing between dikes within a system. Optimum design would be the maximum spacing providing a satisfactory navigation channel alignment and adequate depth.

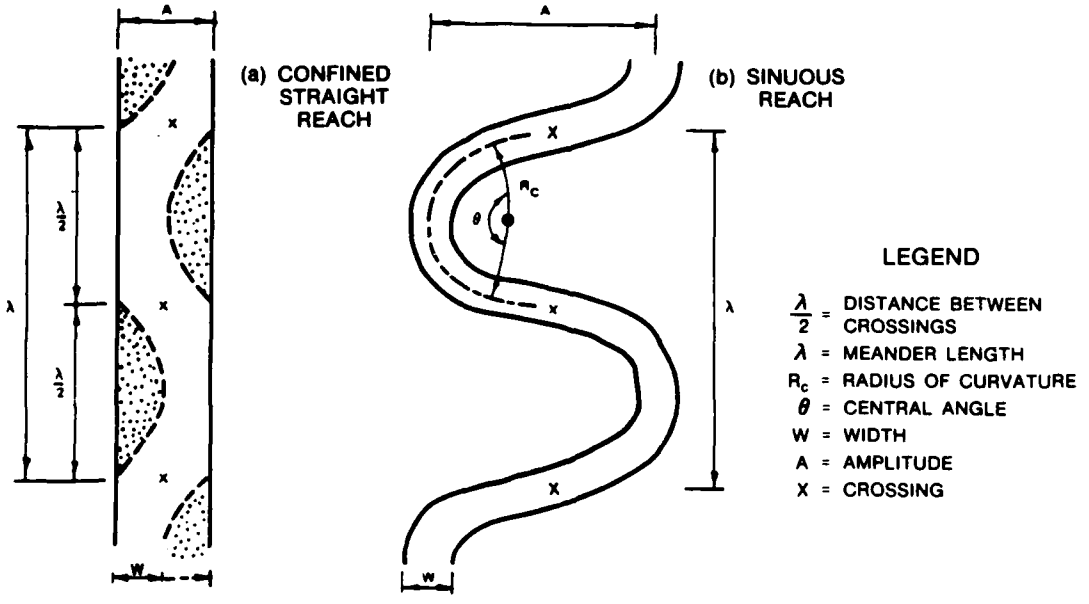
manual this year. The results will include guidance for safe widths on 30-, 45-, and 60-deg bends. Determination of the effects of wind, waves, and currents on navigation at entrance channels is under way using a new computer simulation concept. Development of the basic analytical and mathematical models is under contract. Development of the mathematical model for vertical vessel motion has been completed, and formulation of the mathematical model for horizontal vessel motion has been completed. A final report and user's manual on vertical ship motion were completed in FY 85. The development of the computer code for horizontal motion will be completed in FY 86.

Work is progressing to develop design criteria which can be used to select the type of dike needed for particular application to constrict or stabilize the low-water navigation channel for maximum efficiency and minimum environmental effect. Such parameters as the most effective dike profile, height, angle, and spacing in river crossings are being investigated. Base structures studies and testing to determine the effect of dike height, crest profile, and angle were accomplished. Investigation of the effect of dike spacing on development of

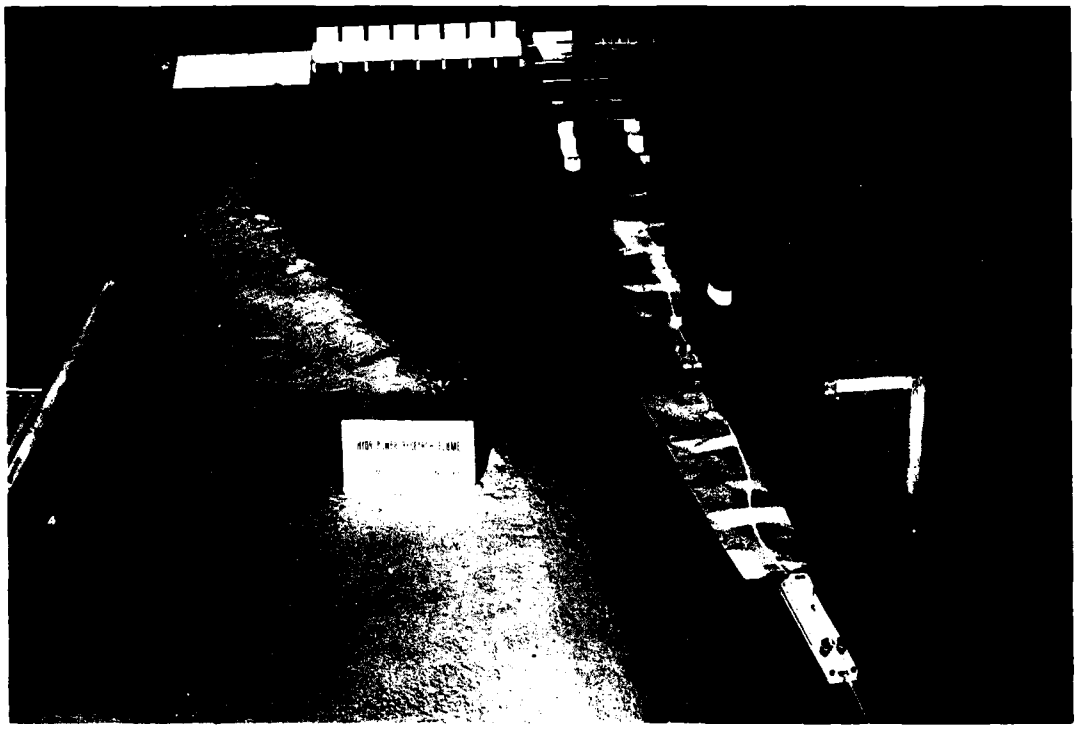
navigation channel depths in crossings is planned for completion in FY 86. All findings of the work unit will be included in Chapter 7 of the "Layout and Design of Shallow-Draft Waterways" engineer manual next year.

Additional research is being conducted to integrate the velocity and current direction mathematical models, tow maneuvering models, and real time tow simulation into an overall simulation of pilot, tow, and flow interactions to supplement and complement the physical modeling effort concluded earlier. This brings the pilot into the control loop and allows a rational approach to evaluate the effect of the human element in the determination of safe and efficient shallow-draft navigation channel design. A video tape describing the simulator and its applications was prepared and distributed in FY 85. Tug and fender forces modeling capabilities were added to the simulator to allow the modeling of lock walls, bridge fenders, and helper boats. Prototype maneuvering tests were conducted in conjunction with the Coast Guard to refine the coefficients for barge tows used in the simulator. This model has already produced very realistic results, increasing our knowledge of ship maneuvering and navigation channel design. The fully refined tow simulator model will result in considerable cost savings and improvement of safety of navigation channels for the Corps and its Districts in the area of navigation channel design.

Research is required to develop criteria to ensure the most economical and stable channel alignment for both navigation and flood purposes. The RIVERS '83 conference was held, and the proceedings, containing papers on various aspects of meandering, were published. Several useful concepts and theories have been formulated from a review of these proceedings and other technical papers.



Planform parameters which affect stable channel alignment.



Tow navigating into the lock approach with a steady-state powerhouse discharge.

The validity and usefulness of the various theories are being checked by an analysis of prototype data. Contracts are being let to several universities to aid in the prototype data analysis, and to look at the theoretical mechanics of flow in alluvial river and the relationship to channel geometry.

Work is ongoing which addresses the critical need for design guidance in locating hydropower plants at both existing and proposed Corps projects. A 1:70-scale physical hydraulic model is being used to develop design criteria for location, orientation, auxiliary structure requirements, and operational procedures to minimize the effect of hydropower generation on navigation. The testing facility, including all appurtenances and instrumentation, has been completed. A three-phase testing procedure will be conducted on each of three selected channel cross sections. The three-phase testing will determine the maximum safe surge height from a powerhouse station; the relationship between powerhouse release, channel cross section, and surge height; and the effect of powerhouse releases on sediment deposition in the lower lock approach. Maximum safe powerhouse releases for the first channel size and one powerhouse location were determined in FY 85. Completion of all phases of testing will be completed in FY 87. A final report presenting study results and the guidelines derived will be published in FY 88.

Hydrology of cold regions

Cold region hydrology considers those aspects of northern hydrology which deal with the influence of snow, seasonal and perennial ice, and freezing,

thawing, and frozen soils upon the spatial and temporal patterns of the hydrologic cycle.

Present R&D includes:

1. Development of techniques to measure and monitor soil moisture beneath snow cover and in frozen-unfrozen ground, and to monitor the water equivalent of the snowpack, river stage, and environmental parameters such as snow water equivalent.
2. Watershed research in Alaska to quantify the influence of frozen ground and organic soil covers upon snow and liquid precipitation runoff processes.
3. Development of field procedures and measurement of data on sediment transport and aggregation and degradation in northern rivers.
4. Development of modeling capabilities for mobile bed rivers.

A radio frequency soil moisture sensor, a soil tensiometer/transducer, and an improved snow pillow system have been designed and laboratory and field tested under freezing, thawing, and frozen conditions. Soil moisture, snow water equivalent, and precipitation data are being incorporated into the SSARR model using the Sleepers River watershed in northern Vermont. Hydrometeorological sensors have been interfaced with Landsat and GOES satellites and Meteor Burst telemetry data relay systems. The following parameters have been received from the GOES system at 4-hr increments over the past 3 years: soil temperature, soil tension, snow water equivalent, and wind speed. The snow triangle method to obtain snow water equivalent data has been placed at two sites in New England. Sensors to measure river stage under ice cover have been evaluated. These new data bases provided by the near-real-time capabilities for data collection are resulting in modifications of existing models and field methods that will contribute to improved costs savings and benefits on Corps projects. In Alaska, snowmelt runoff, winter base flow, and water storage in icings are being measured under different types of ground conditions.

Ice engineering

The Ice Engineering Program addresses four major problem areas:

- Hazardous winter inland navigation.
- Severe winter floods.
- Loss of hydroelectric-generating capacity in the winter.
- Ice damage to shorelines and shore structures, which includes Corps structures and plant.

The Ice Engineering Facility has proven to be exceptionally valuable for conducting ice engineering research. Complex natural icing phenomena are modeled in the laboratory permitting detailed study of ice under controlled conditions. Such laboratory studies lead to deeper understanding of basic ice processes, leading in turn to the development of fieldable ice control measures.

A physical model study of Cazenovia Creek was completed in FY 85, and the model is still being used for ice jam and ice retention studies. Ice engineering research has produced air screens to keep floating ice out of navigation locks, air bubblers to minimize ice formation on lock walls, protective devices for underwater intakes, ice booms to minimize ice jam flooding, and improved design criteria for structures that must withstand ice forces.

The "Ice Engineering Manual" was completed and published 15 October 1982. It has had two printings and an appendix added. Currently is it undergoing major rewrite.

Environmental Quality

Environmental impact

Environmental impact research includes field studies of environmental effects, evaluations of existing data and information, demonstrations of resource management and protection techniques, development and verification of assessment and predictive techniques, development of environmental resource classification schemes useful in impact assessment, and preparation of field guidance.

The final product of the work concerned with habitat evaluation methods is a looseleaf notebook containing information on method selection and application; model availability, construction, modification, and testing; sampling methods; software availability; and sources of assistance. In developing methods to evaluate the impact of changes in estuarine circulation on water quality, test application of a two-dimensional, laterally averaged model in the Savannah River estuary was completed and test application of a multiple-box model to the Mobile Bay/Mississippi Sound area was initiated. A draft of a visual impact assessment procedure was completed under contract; it was reviewed and field

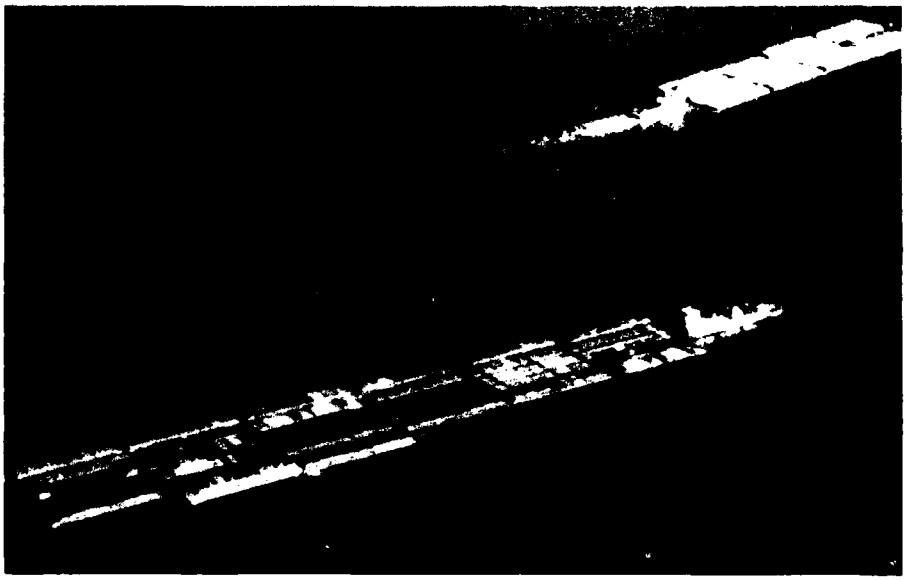
Environmental monitoring activity at a Corps project.

Habitat quality—a factor in impact assessment.

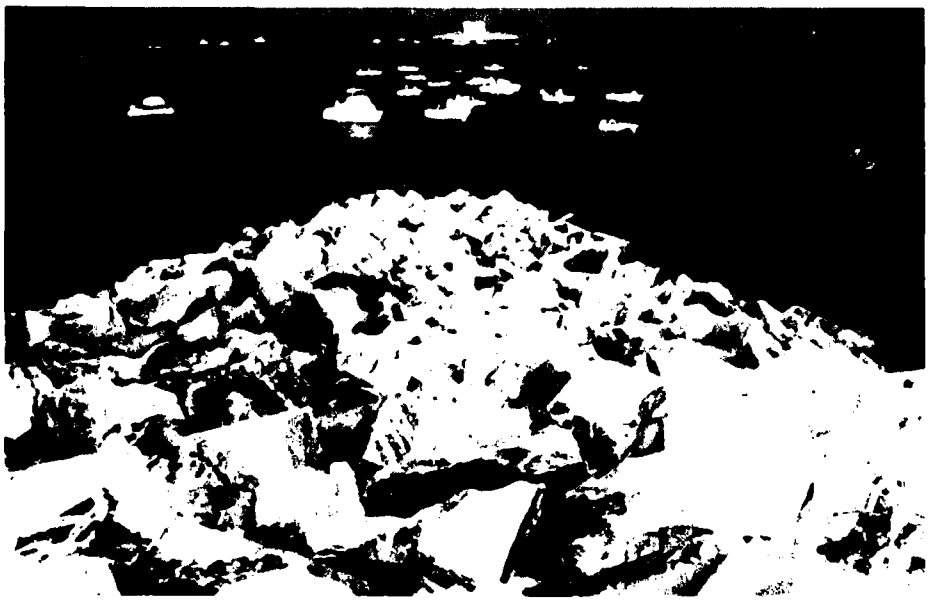
Erosion processes at reservoir shorelines in cold regions studied in the New England area.

tested in four Districts. Results of an August 1984 workshop to plan a course of action to develop an environmental monitoring procedure was compiled into a report containing a draft plan of study, and this was circulated for review and comment. To predict erosion potential of shorelines in cold regions, five reports were prepared during FY 85 on bank erosion measurements and processes. Field studies of erosion rates and processes continued at three sites.

The study of the effect of channel deepening and jetties on aquatic species involved publication of five new species profiles, two workshops for Corps personnel, and initiation of a field study at a small boat harbor in Alaska. Results achieved in FY 85 in the study of the ecological effects of rubble structures were similar: publication of a technical note, presentation of research results at a workshop, and surveys/sampling at two field sites. The work on beach and



Physical and biological effects of commercial navigation activities in waterways are being assessed.



Rubble jetties usually have beneficial impacts on biological resources.

foredune ecology involved a field study in Florida addressing the problem of effects of beach nourishment on sea turtles and seven other prenourishment or postnourishment field studies in Florida, North Carolina, and Washington State. Technology transfer was also accomplished through workshops and seminars.

A major user's manual was published providing extensive guidance to the field on techniques for vegetatively restoring problem soils at Corps construction sites. An interim manual on wildlife resource management, containing about 70 reports, was completed and submitted for review. Several technical papers were presented on the work unit and three issues of the information exchange bulletin were published. To determine techniques for preserving cultural sites, an interim manual was prepared under contract using results from previous studies by the contractor, a literature review, and results from an extensive interagency survey at the Federal and state levels. The manual will be published early in FY 86. Still another manual was prepared providing guidance on seagrass planting, and in this subject area, a field study was initiated to investigate fertilizer effects. Findings to date were reported at a coastal ecology workshop. At CRREL, two field sites were established to study plant establishment on sandy soils in cold regions, and field and greenhouse studies were continued to evaluate various plant species. Review comments were received from field offices on draft guidelines for revegetating construction sites in cold regions.

Wetlands

This research has identified the need to develop improved and standardized techniques to (a) assist field personnel in the identification and delineation of wetlands subject to jurisdiction under the Section 404 regulatory program, (b) assess and quantify wetland values for use in the evaluation of permit requests, and (c) meet Corps needs in planning, construction, and operational activities in wetland areas.

Between FY 78 and FY 82, research on wetlands identification and delineation was sponsored primarily by Operation and Maintenance General Funds, with additional funding provided on a case-specific basis by Corps Districts.

Provision of habitat—an important wetland function.

Hydrology is the prime wetland delineation factor.

Vegetation is one indicator used in wetland delineation.

Soil is another wetland delineation factor.

Research has provided a legally defensible technique for the delineation of wetlands that has subsequently reduced time that might otherwise be spent in litigation. This technique, based on field identification of vegetation, soil, and hydrologic features, improves the efficiency of field inspectors and minimizes time spent in field determinations. The technique has been documented in a draft wetlands delineation manual that has been field reviewed and is now being revised.

Planning methodologies

Activities in this program address problems facing Corps planners in the performance of their mission. Economic analysis techniques, forecasting, data use, spatial data management, and water transportation analysis techniques are emphasized. Products include technical reports, guide manuals, computer programs, user manuals, and documentation.

Prior accomplishments include the development of three regional impact computer models and their associated user's manuals applicable to navigation projects. An industrial location/community attribute computer model with associated user's manuals is operational and is available for use. A survey of construction workers has been completed and procedures for estimating employment benefits have been developed and disseminated to the field.

Work also includes development of techniques for estimating external economies at Corps projects, development of a "National Economic Development Evaluation Manual" for recreation, and development of a manual for deep-draft navigation. An evaluation of the commercial and industrial flood damage assessment procedures has been completed. The economic procedures for floodplain evacuation and relocation have been developed. A questionnaire and test of the contingent valuation technique and user manual were developed.

Additionally, a needs assessment for a forecasting system package was performed, and a framework for constructing a forecasting system was developed. A small area forecasting model is operational. A land use analysis model using spatial data is operational. Methods for assessing the expected cumulative environmental impacts associated with induced development have been formulated. Spatial data management software and analysis models have been developed and applied in planning studies. Spatial data bank creation and management software have been tested and documented. A triangular terrain-based data capture system has been implemented.

Analytical techniques

The improvement of basic methods of evaluating hydrologic phenomena and analytical techniques in the planning process is the objective of this research program. Continual improvements are being made in the basic techniques as required by the field office projects. Evaluation of today's many alternatives demands accurate and efficient procedures capable of processing large amounts of data. Effective utilization of the computer makes it possible to assemble, store, retrieve, and analyze the data required for these hydrologic and planning analyses.

Analytical planning techniques are being developed to relate hydrologic, economic, and environmental parameters directly to geographic data such as land use. Such techniques provide a continuing medium for use by Corps and local planners and engineers to analyze the impact of management measures. The energy problem is being addressed through new and improved techniques for sizing hydropower plants, allocation of reservoir storage to competing demands, and operation of reservoir systems to best meet multiple objectives. Hydrologic

and hydraulic analysis techniques are being developed to assess dam safety and develop dam failure evacuation plans for those dams which are a threat to life and property.

Water supply and conservation

With the development of the water conservation procedures manual came new requirements for application handbooks and better forecasting procedures. Three publications were produced relating directly to the manual: an annotated bibliography with specific references to the steps of the manual, an assessment of forecasting techniques, and a bibliography on forecasting techniques. A computer-based set of forecasting techniques was chosen for use by Corps planners and installed on the Corps' central computer library. The model, known as IWR-MAIN, will become the Corps' standardized procedure for forecasting water demands. To aid planners in producing better water supply forecasts, two publications were completed:

- A handbook of methods detailing how to obtain acceptable forecasts under varying data conditions.
- An interactive user's guide and manual for IWR-MAIN.

To further aid in evaluating the benefits of water conservation and to ensure that water is available during drought conditions, three new reports were published and distributed to the field:

- A study describing the influence of price and rate structure on future water demands.
- An evaluation of drought management measures for municipal and industrial water supply.
- A prototype application of the drought management optimization procedure. A handbook demonstrating how to apply the procedure described in the water conservation evaluation manual was completed. The IWR-MAIN system was converted to run on an IBM-PC.

Major products through FY 86 include, "Guide Manual for Preparing Water Balances," "Survey of Conjunctive Use," "Comparative Analysis of Groundwater Formulations," and "Water Supply Simulations Using HEC-5."

Another significant activity centered on developing the MAPS program to provide the capability of evaluating water supply source alternatives with cost modules. A water conservation subroutine has been added, and the program was modified to improve a number of existing applications. Cost-estimating routines have been verified against actual construction costs. An engineer manual on planning and designing small water systems was completed. A method for estimating the costs of surface water intakes was developed. Techniques for determining when to repair or replace pipes were identified and evaluated and an engineering technical letter prepared. Work was completed on development of an algorithm for estimating water reductions resulting from implementing water conservation measures.

Risk analysis

This is a new study, initiated in FY 85, for which relatively little formal research had been conducted, other than the initiation of a literature survey. This

survey was part of an inquiry designed to provide guidance and workable risk analysis methods in evaluating dam safety problems in a manner compatible with sound engineering practices and risk-cost evaluation principles.

Surveying and Satellite Applications

Surveying and mapping

This program includes work for improving land, hydrographic, and airborne surveying and mapping capabilities within the Corps of Engineers. Most of this work is performed in the coastal regions and navigable waterways of the nation.

In the coastal zone, survey data are required in the beach, nearshore, and offshore areas. Coastal surveys are costly, time-consuming, frequently difficult or impossible to obtain, and often lack sufficient accuracy in the surf and nearshore zones for many coastal engineering applications. Therefore, a significant need exists for alternative means of obtaining coastal survey data that accurately handle the entire profile, are rapid and inexpensive, and that utilize a datum other than the water surface. The estimated annual hydrographic surveying and mapping workload of the Corps is approximately $41 million. The cost of surveying is one of the major expenditures in any coastal project or monitoring program.

Hydrographic surveys are routinely performed along the nation's waterways in order to compute the volume of material removed by dredging contractors. This volume is then used as a basis for payment to the contractor. The computational method used is the average-end-area method, or some adaptation of this technique. Quite often the data collection procedures do not coincide properly with the computational method. The objective of this work is to develop the best method for determining the volume of material removed by channel dredging.

Efforts are also continuing to monitor technological advances in hydrographic surveying for possible adaptation to Corps needs. Recent emphasis includes preparation of a report on available methods for heave correction and development of a fully automated small boat survey system.

Remote sensing

There has been a tremendous advance in the state of the art in the remote sensing field over the past 10 years. Many of the sensor systems that have been or are being designed measure terrain and hydrologic and environmental conditions more accurately. With trends of ever decreasing funds and manpower, remote sensing technology probably provides the only opportunity of managing and analyzing the nation's water resources.

The Atlantic Remote Sensing Land-Ocean Experiment (ARSLOE) was successfully completed. This field experiment developed a data base for comparing remote sensing techniques versus in situ measurements. The preliminary results of the Remote Orbital Wave Spectrometer (ROWS) demonstrated the detection of surface currents. The High Frequency Radar (CODAR) demonstrated potential for gathering two-dimensional wave spectra and current vector data. (This field experiment involved over 30 organizations for 2 months of coincident remote sensing and in situ systems wave data. The evaluation of 58

aircraft missions of four ground-based radar systems was accomplished.) Several papers were presented at the OCEANS '82 Conference on ground truth experiments during the ARSLOE experiment.

Data were analyzed from an experiment at the Corps' Field Research Facility with a coherent wave radar to test the feasibility of measuring surface currents in the surf zone. Coastal Engineering Technical Notes were written on surface current measurement using a microwave scattermeter and on sensor selection for wave data.

In FY 84-85, a successful field demonstration of the CODAR surface current mapping capability was conducted on the Delaware Bay in a joint experiment with the National Oceanic and Atmospheric Administration's National Ocean Survey. A workshop on radar detection of waves was presented for District personnel. A CODAR field test for wave measurement was conducted at the Field Research Facility.

A literature review of state-of-the-art in situ measurement techniques for hydrologic and environmental monitoring was prepared, and a subsequent report was completed. A sensor package complete with interfaces for measurement of wind speed and direction, solar radiation, air temperature, barometric pressure, relative humidity, soil moisture, precipitation, and snow water equivalent was developed and installed at sites in the New England Division and the Detroit District.

Construction, Operation, and Maintenance

Operation and maintenance management

This program supports command goals to provide modern, integrated, automated office systems to a diminishing workforce, thereby improving productivity and efficiency. The Corps-developed automated budget system, EDITOR, was installed at over 30 Districts for use in the FY 86 budget preparation.

Energy

This program was initiated in FY 83 with an ongoing study of techniques to reduce petroleum energy consumption in Civil Works operations. To date, the Civil Works petroleum-consuming activities have been identified by mission area and the present level of consumption determined. Overall, petroleum consumption accounts for about 90 percent of Civil Works energy consumption. A survey of potential alternate fuels was completed, and candidate alternate fuels were identified for Civil Works activities where feasible. A report describing these alternate fuels and usage considerations was written in FY 84. A further study of these fuels as applied to large, medium-speed diesel engines, such as used by Corps floating plant, was completed by the Army Fuels and Lubricants Research Laboratory. Initial steps were taken to begin an alternate fuels usage demonstration. A report was also written in FY 84 outlining energy conservation technologies applicable to Corps dredges. The Civil Works Energy Data System is intended to provide District engineers with a microcomputer-based tool to manage energy consumption at the District level. Software has been written to

manipulate project and District level energy consumption data and to facilitate Defense Energy Information System (DEIS) input. Application of alternate energy technologies to Civil Works processes and facilities was initiated in mid-FY 84. The goal of this work is to reduce energy consumption of nonpetroleum-consuming Civil Works activities through the use of alternative energy technologies.

Improvement of operation and maintenance techniques

The magnitude and complexity of the Civil Works O&M activities which now exceed $1 billion annually demand that the program be managed with maximum efficiency. To reduce the annual O&M fund requirements, it is imperative that positive action be taken to effect maximum economy with minimum use of energy in all activities. These objectives can be attained only if rigorous and direct research and development effort is continued in several critical fields of activity using state-of-the-art scientific and engineering knowledge to develop systems, techniques, and improvements to ensure maximization of operational and maintenance efficiences. There are several areas associated with present operation and maintenance activities where efforts are being made to develop and adapt new operational techniques to effect significant savings in the program. Approximately one third of the annual O&M activities are in dredging of material deposited in navigation channels and harbors and 40 percent is for all dredging activities. Any methods to prevent or reduce the shoaling have the potential for significantly reducing the cost of dredging. A need exists for inexpensive evaluation procedures for projects where relatively small amounts of O&M funds are involved. Large O&M projects can be reduced in cost through the use of more elaborate procedures to evaluate alternatives accurately.

The availability of definitive impacts of structural alternatives can be used to reduce maintenance dredging. Improvements and increased knowledge can be used to decrease dredging requirements. An improved understanding of alternatives for dredging will allow the most cost-efficient approach to be chosen. Environmental concerns can be addressed with new equipment, new techniques, and an understanding of the behavior of existing dredging systems. Improvements to dredging systems can have a direct impact on reducing dredging costs. Several areas of O&M activities can be reduced in cost through a better understanding of present procedures and development of new procedures and equipment.

Laboratory testing of high density polyethylene (HDPE) pipe was completed, and field testing on a dredge was initiated. A 30-in. HDPE pipe was installed on the Port of Astoria's dredge OREGON where it will be subjected to a season of sand pumping. A draft engineer technical letter on the use of HDPE was completed and sent forward for review. Several Environmental Effects of Dredging Program Technical Notes were prepared documenting both laboratory-testing procedures for predicting potential contaminant release during dredging and methods for dredging contaminated sediments. Prior evaluation of resuspension by hopper dredges was extended by use of data from a recently completed Japanese study. A classification system for rating dredges according to their ability to dredge contaminated sediments with the least environmental impact was completed. A third volume of an annotated dredging bibliography was published.

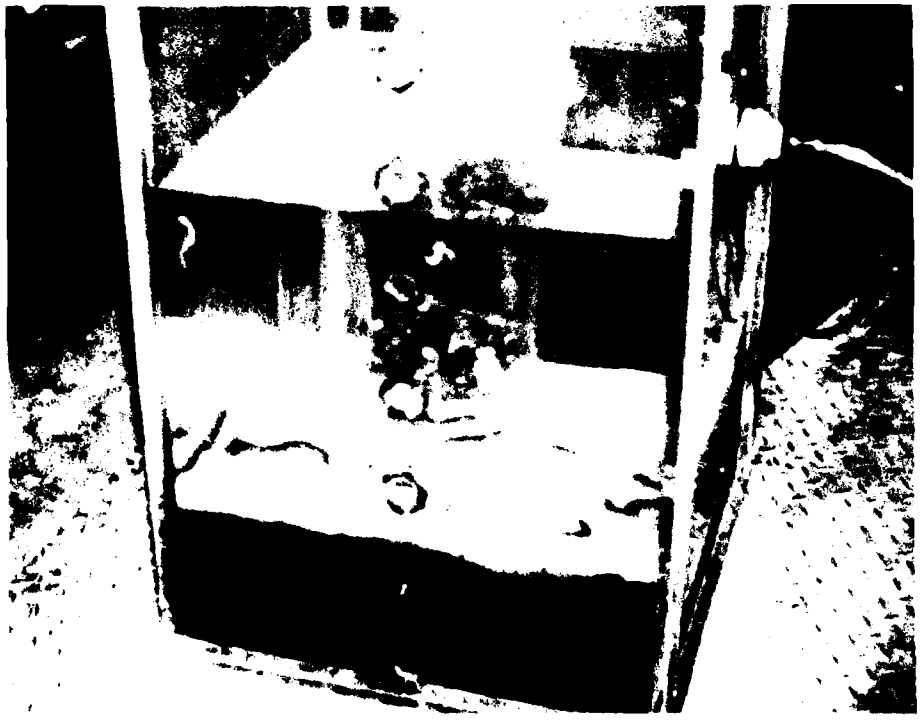
Hand-held ultrasonic wall thickness gage measures the wear of HDPE pipe.

Field and laboratory tests of fine sediments have revealed important information concerning the way that these materials form shoals. Research results have been successfully applied to site-specific studies of shoaling in Corpus Christi Harbor and open water dredged material disposal in San Francisco Bay. New expressions for settling and consolidation of sediments were developed for implementation in the TABS-2 and TABS-3 numerical modeling systems. Research into new techniques to measure in situ density of bed sediments resulted in creation of a new work unit to complete that research. Work began on evaluating resuspension of fine sediments under waves. Material was supplied for a new engineer manual on sedimentation. Past work in advance maintenance dredging has resulted in several technical reports and other technology transfer, including an engineer technical letter (ETL 1110-2-293, "Shoaling Predictions in Offshore Navigation Channels, Analytic and Empirical Methods"). Two additional draft engineer technical letters and a technical report on advance maintenance were completed in FY 85. TABS-2, a complete system of numerical models for two-dimensional numerical modeling of navigation channel flows and sedimentation, has been developed and released to the Corps offices. This system, which includes a 700-page user's manual, has been enthusiastically received by the field offices and is already in use at five locations in addition to WES. It has already been applied to nearly two dozen sites. Telephone support to non-WES users was provided on a continuing basis. Two Huntsville Training Division courses were conducted on the system's use. A set of three-dimensional numerical models was developed and successfully applied to New York Harbor for the New York District. A survey of existing estuarine training structures was completed and results were compiled for analysis. A draft engineer technical letter on present use of training structures was prepared.

Long-term effects of dredging operations

The Corps is legislatively required to evaluate and minimize the environmental impacts of dredged material disposal and/or placement of fill that are associated with the Corps' dredging and environmental regulatory programs. Dredging operations to maintain the nation's approximately 25,000 miles of Federal channels, over 100 commercial harbors, and over 400 small boat harbors comprise the largest single line item in the total Corps budget and account for approximately 39 percent of the general budget. (The Corps' dredging mission requires the annual disposal of 250 to 300 million cubic yards of dredged material.)

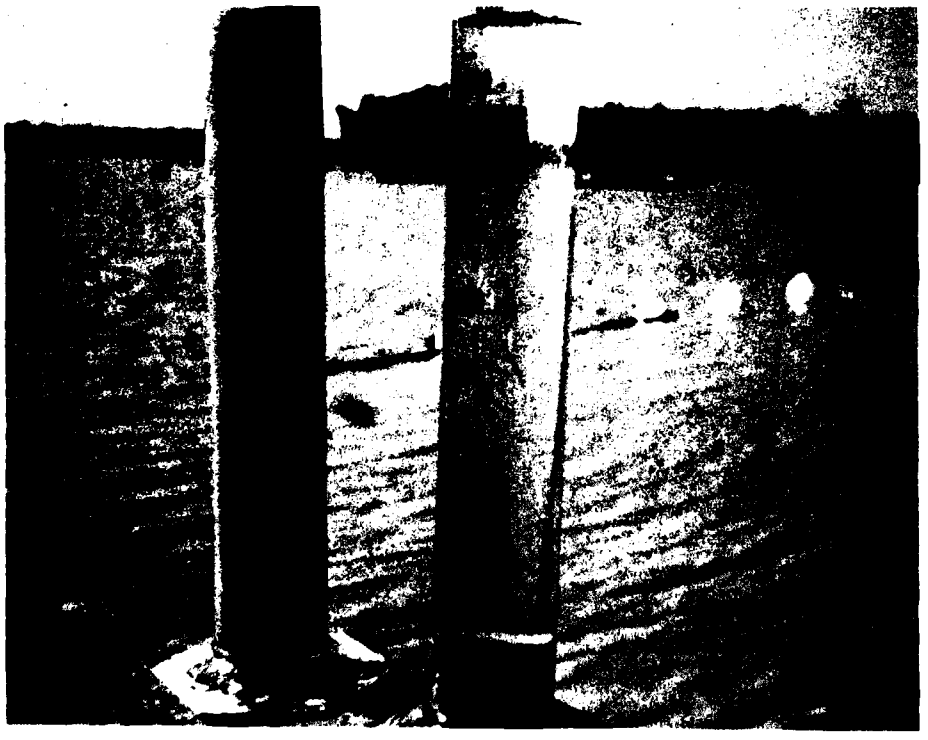
Research conducted during the Dredged Material Research Program and the Dredging Operations and Technical Support Program has established that the mere presence of a contaminant in a sediment does not indicate that environmental harm to the aquatic system will result from dredging and aquatic disposal of the sediment. Therefore, chemical analysis or inventory of sediments cannot be used as a basis for predicting potential impacts but can only indicate the presence of potentially harmful contaminants. First-generation methods have been developed to provide the field with reliable indicators of potential harm. Consequently, first-generation biological testing procedures were developed to identify and to assess the environmental impacts. These evaluative procedures were based on limited laboratory and field data; consequently, the accuracy of the procedures with regard to actual field conditions/effects must be more definitively



Laboratory bioassay test of effectiveness of capping contaminated dredged material.

established. Because different data interpretations exist among the various environmental resource and regulatory agencies (e.g., Corps of Engineers, Fish and Wildlife Service, Environmental Protection Agency, National Marine Fisheries Service, and state agencies), no single technical procedure is acceptable to all regulatory agencies for interpreting test results. Comprehensive methods for evaluating cumulative effects of continuing disposal at one or several disposal sites do not exist. The Corps has conducted limited field tests of procedures to eliminate or minimize adverse impacts of dredged material disposal through capping contaminated material with noncontaminated material in conformance with the legal provision for capping contained in the international London Dumping Convention. Laboratory studies of the biological, chemical, and physical aspects of capping were initiated along with a survey of the engineering aspects of capping. Studies on the bioaccumulation, environmental interpretation of consequences of bioaccumulation, and biomagnification of toxic substances in aquatic organisms were continued with work on the biomagnification of toxic substances in aquatic organisms completed in FY 84.

Additionally, methods were developed to size containment areas to minimize the discharge of suspended solids in the effluent. The sizing procedure was not designed to predict contaminant concentrations in the effluent, nor did it account for geochemical changes that will occur with time within the containment areas. Studies were initiated to predict effluent quality from diked containment areas. Under the Dredging Operations and Technical Support Program, limited work



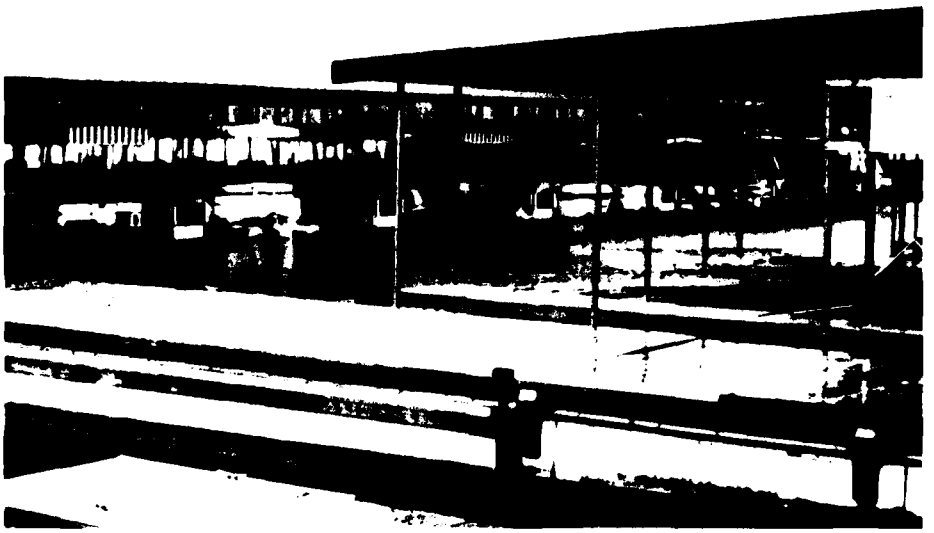
Field test to determine quality of water discharged from dredged material disposal areas.

was initiated to predict the potential mobility of toxic substances into plants from contaminated sediments. Laboratory studies were initiated and generally limited to site-specific projects, and first-generation tests procedures were developed that require verification. Contacts have been made with foreign researchers in this area for incorporation of their data bases into the work unit on toxic substances bioaccumulation in plants. In FY 84, a modified elutriate laboratory test was developed that provides an indication of contaminant levels in effluent from confined disposal areas. Field studies were continued to verify the procedures for determining contaminant levels in effluents. Development of an interim technique for predicting contaminant levels in disposal area effluents was completed in FY 84 along with initial mixing zone guidance. Additionally, in FY 84 work on the freshwater and saltwater plant bioassay test for determining toxic substances bioaccumulation was continued.

In FY 85, draft technical guidance on the development of predictive techniques for estimating effluent quality in diked containment areas was completed. Initial mixing zone guidance was refined.

Natural resources

The Corps of Engineers is mandated to provide recreational opportunities for the general public and to maintain the natural resources for future generations at its water resource development projects. Carrying out these requirements, while adhering to new directives regarding reductions in budgets and personnel, has fostered an even greater need for research. Visitation to these projects has continued to increase, indicating the public's acceptance of these developments. The increasing significance of recreation area development and operation associated with the Corps' existing projects has focused attention on the need for improved methodology in the planning, design, construction, maintenance, and operation of Corps-controlled recreation and related natural resource areas.



Marine facilities at Corps projects.

Plant-growth regulator reduces mowing in a recreation area.

To assist resource managers and planners, a handbook on computing cost-effectiveness of alternative sanitary facilities was developed and distributed. Program-developed performance standards, useful in developing O&M contracts, have assisted Districts in their contracting endeavors and in determining hired labor needs. A system of cost tracking for recreation area maintenance has been developed which enables managers to determine costs for conducting various maintenance tasks. Once costs are determined, this information can be used to increase efficiency or to estimate potential contract costs.

One of the methods used in managing recreation and natural areas is communicating with the using public. Guidelines for the use of interpretation as a management tool have been well received at Corps water resource projects. As a result of feedback from project personnel, a number of supplements to the original guidelines were distributed. Implementation of various interpretive tools will lead to lower maintenance costs and improved visitor relationships. Requests from other Federal and state agencies have indicated a wide interest in this accomplishment. In addition, several universities are using the guidelines as resource materials. Efforts in the area of visitor safety and security have led to the development of improved administration of law enforcement contracts. Weaknesses in the design of recreation areas which contribute to increased incidents of crime have been isolated, and techniques to overcome some of these flaws have become available. This study also revealed situations which contribute to the public's perception of security. Where appropriate, findings were tested within the

Corps recreation campground facilities.

recreation research and demonstration system for suitability for Corps-wide adoption.

Increased emphasis on recovering O&M costs through user and entrance fees is being addressed. Close coordination with other Federal and state agencies is being maintained to prevent a duplication of effort. Benefits of this effort will include optimal methods of collecting fees which have been developed by other agencies and are adaptable for use by Corps management. The amount of revenue produced will depend upon the options implemented and the authority for implementation.

The increased use of microcomputers at the project level has produced the need to increase efficiency in the software programs developed by reducing duplication of effort. Savings in manpower and funding will be evident as this effort progresses. Upcoming accomplishments within the next 3 years will enable the Corps to economize on the management of their recreation areas through more efficient scaling of developed areas, better data for determining park consolidation and/or closures, and more efficient vegetation management.

Water quality

The water quality program is a new R&D initiative for FY 86. Because of its broad mission, there has been extensive coordination during its initial planning to minimize overlap and eliminate duplication of effort. During the formulation of this program, the Wastewater Management Program, which was concerned with analytical methods, was incorporated into the Water Quality Research Program. Previous accomplishments of this work include automation of water quality laboratories from both a hardware and software standpoint, a survey of Corps water quality laboratories, and guidelines on chemical systems information networks and laboratory operations.

Part IV
CONCLUDING REMARKS

In the short term, the Corps of Engineers does not expect any significant mission changes in its Civil Works functions and responsibilities. However, it is expected that there will be a continuing strong R&D emphasis:

1. On Corps operations and maintenance related research and development to provide Corps field offices with improved methods and technologies and cost savings.
2. On dredging operations to achieve cost reductions and improvements in this important activity.
3. To explore and apply a wide variety of remote sensing techniques to Corps Civil Works missions to achieve greater efficiency and cost saving.
4. On navigation and flood control activities.
5. To continue improvement of Corps capabilities in coastal engineering.
6. To improve the environment with emphasis on management and conservation of natural and cultural resources.

END

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DTIC